THE MORPHOLOGY, MINERALOGY AND GENESIS OF TWO SOUTHERN NEW ENGLAND SOILS

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The Morphology, Mineralogy and Genesis of Two Southern New England Soils

G. A. Bourbeau[1] and C. L. W. Swanson[2]

The ultimate purpose of the inventory of our soil resources is more efficient land use. Our population is increasing geometrically. Our food production curve is rising arithmetically. Therefore, any additions to our knowledge of the "soils that support us" is vital. In recent years, new techniques have made possible a more complete "analysis" of our soils and an appraisal of their maximum exploitation capacity for society without depletion.

This paper is offered as an example of such an "analysis". At the same time, it is offered as a contribution to our national system of soil classification, which is essential as a sound basis of soil classification for our country and for the rest of the world. The soils chosen for study are important in Connecticut and in New England, but the ultimate objectives should be of universal application.

Two soil series, the Merrimac and Wethersfield, were chosen for these studies. The Merrimac is a particularly important soil in the Connecticut Valley and in New England, and to a lesser extent in New York. The Wethersfield is more limited in area, occurring principally in the Connecticut Valley in Connecticut and Massachusetts. Information on the characteristics of these soils is useful in improving their management for increased and sustained crop production.

In the Valley, the Merrimac soils are widely used for shade-grown, Havana Seed and Broadleaf tobacco, and for vegetables; the Wethersfield soils are used for dairy farming, vegetable crops, and Broadleaf tobacco. Additional information on the physiography, drainage, geology, parent materials, climate, vegetation, and certain physical and chemical properties of these soils is presented elsewhere (47).

A predominant soil type of each series was selected for detailed study in the field and laboratory; the Merrimac fine sandy loam formed on glacial outwash material derived from granite, gneiss, and schist, and the Wethersfield silt loam developed on compact till derived from Triassic sandstone, shale, and siltstone. The Merrimac may be considered a modal Brown Podzolic but assigning the Wethersfield to this great soil group has been questioned (47).

HISTORICAL

According to Flint (15, 16), the Cary ice sheet stagnated and, upon melting, formed glacial Lake Hartford in the Connecticut Valley. This lake extended from Middletown, where the Connecticut River was

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dammed by glacial drift, to the north beyond the Connecticut-Massachusetts border. The floor of the lake was predominantly glacial till. Later, terraces were formed and varved clays deposited on the till. Merrimac soils are now found on the terraces and Wethersfield soils on ground moraine, and especially on drumlins.

Neither of these series was recognized in the soil survey of the Connecticut Valley made in 1899 (12). The Merrimac was probably included in the Hartford sandy loam and the Wethersfield in the Triassic stony loam. It was not until 1906 and 1919, respectively, that the Merrimac and Wethersfield series were established by the National Cooperative Soil Survey of the State Agricultural Experiment Stations and the Soil Survey Division of the United States Department of Agriculture. Morgan published a reconnaissance map, a catena key and descriptions of Connecticut soils in 1930 (36) and a second soils map and report in 1939 (37), which included the soils studied herein. A detailed soil survey of Hartford County, Connecticut, where these soils are predominant, was begun in 1948 (47).

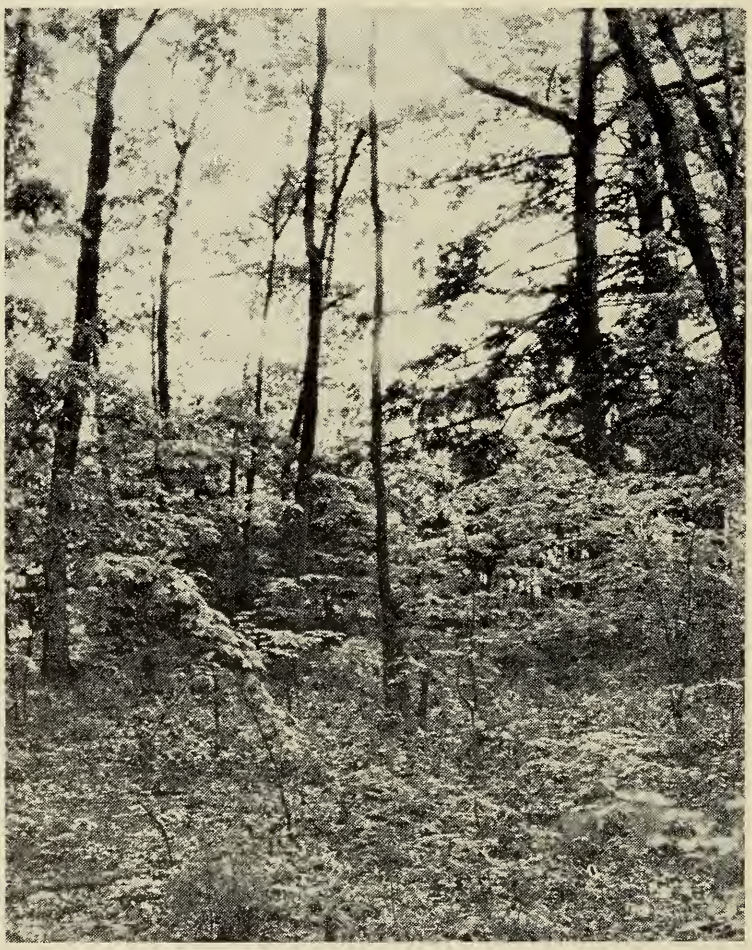

Figure 1. Typical forest vegetation growing on Merrimac soils consisting mainly of oaks with a few scattered white pines, hemlock, red maple, and beech, and a sparse understory of shrubs, and oak and pine seedlings. Location about ¼ mile south of Silver Birch Lake, Griffin Road, Windsor. June 6, 1952.

Studies of soils from New England have been reported from time to time. Physical and chemical analyses of Hermon and Gloucester soils were published in 1938 by Brown and Byers (4). Hermon soils were found to be highly podzolized and the dominant soil-forming process hydrolysis. It was reported that the intensity of hydrolysis was influenced by the permeability of the parent material and further intensified by an increase in the mean annual temperature.

Haddock (19) made a clay mineral analysis of five New England soils in 1942 by the differential thermal analysis method. The colloids showed considerable variation in clay mineral composition. Illite was the dominant clay mineral. The colloids of a Merrimac soil from Massachusetts contained approximately 55% illite, 20% montmorillonite, 5% kaolinite, 5% gibbsite, and 2% goethite. The remainder was probably amorphous material.

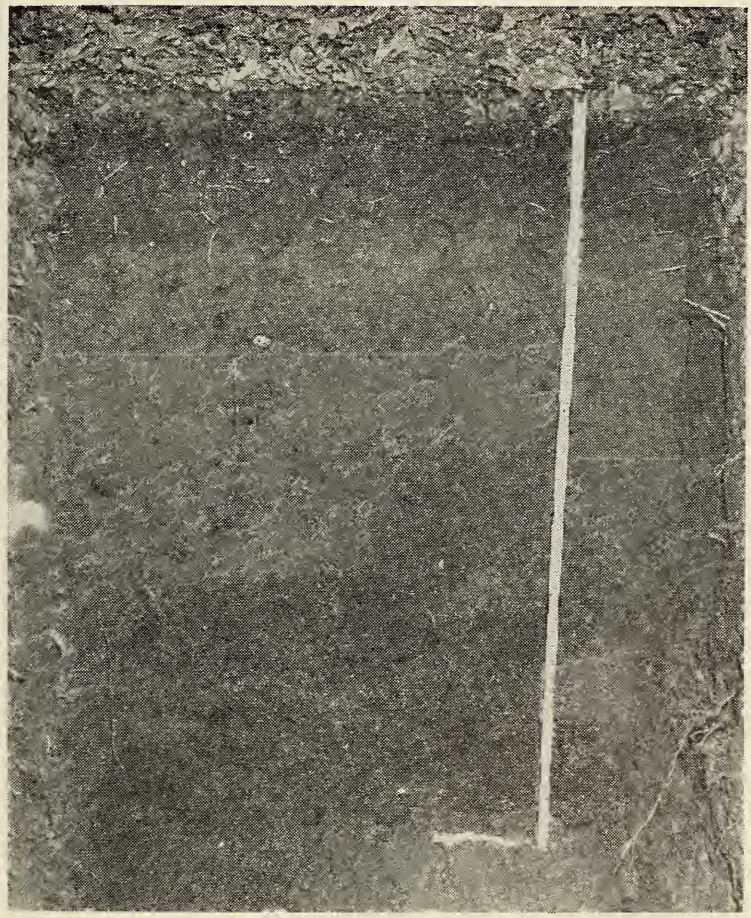

Figure 2. Profile of the Merrimac fine sandy loam sampled for study. An old plow layer (A_p) is covered with about 2 inches of partially decomposed leaf litter. The B horizon extends to about 20 inches, grading into the D. Small and medium-sized roots are fairly evenly distributed throughout the solum; very few roots are in the sand and gravel substratum. Only a few stones or gravel are present in the B with the D becoming more gravelly with depth. This profile was dug in the forested area shown in Figure 1. A detailed description is given on pages 6 and 7.

In 1950 Holowaychuk (23) reported on some clay mineral analyses of the Miami, Hermon, and Worthington catenas. He found illite to be the most abundant clay mineral of the Podzol and Gray-Brown Podzolic great soil groups.

DESCRIPTIONS OF THE SOILS STUDIED

Morphological characteristics of the Merrimac and Wethersfield soils studied are given below. On the basis of field studies, these profiles are believed to represent the modal properties of these soils as developed in this area (44, 47). Photographs of the profiles, vegetation, typical topography and associated land use are shown in Figures 1-5.

Figure 3. A Merrimac fine sandy loam on gently sloping (0-3%) topography cropped to Shade tobacco in background and lettuce in foreground. This area is directly across Griffin Road to the west from the forest area in Figure 1.

Merrimac Fine Sandy Loam

Sample No. S48 Conn. 2-7 (1-10)

Location: About ¼ mile south of Silver Birch Lake, East side of Griffin Road, Windsor, Connecticut. Coordinates on soil profile location map (Windsor Locks USGS[1] quadrangle): No. 5;9.5-B.5;705.

Topography: Nearly level glaciofluvial terrace.

Vegetation[2]*:* Mainly white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), and red oak (*Quercus rubra* L.), with a few scattered white pine (*Pinus Strobus* L.), eastern hemlock (*Tsuga canadensis* L.),

[1]United States Geological Survey.

[2]Grateful acknowledgement is made to H. W. Hicock for assisting in the identification of the vegetation. Scientific names from Gray's Manual of Botany, 1950 edition.

red maple (*Acer rubrum* L.), and beech (*Fagus grandifolia* Ehrh). Sparse understory of low-bush blueberry (*Vaccinium vacillans* Torr.) and (*Vaccinium augustifolium* Ait), witch hazel (*Hamamelis virginiana* L.), bracken (*Pteridium aquilinum* (L.) Kuhn), huckleberry (*Gaylussacia baccata* (Wang) K. Koch.), and oak and pine seedlings.

Drainage: Well drained. Surface runoff slow to very slow.[1] Moderate to very rapid permeability.[2]

Parent material: Stratified glaciofluvial deposits derived principally from granite, gneiss, and schist.

Use: Mixed hardwood and coniferous forest. Evidence of a former plow layer can be easily seen (Figure 2).

Soil Profile Description

Horizon	*Depth*	*Description*
		Duff mull humus type.[3]
A_{00}	2-1″	Undecomposed deciduous and coniferous leaves and other debris.
A_0	1-0″	Partially decomposed organic matter.
A_{11}	0-2″	Very dark grayish brown (10 YR 3/2)[4] fine sandy loam; high in organic matter; soft and spongy; tends to break out into coarse plates as it is well matted with roots. An incipient gray (*Bleicherde*) layer is present in places at the bottom of this horizon but it is discontinuous, appearing more frequently under coniferous vegetation; pH 3.7. Very rapid permeability.
A_{12}	2-3″	Transition layer consisting of interfingering of A_{11} and A_p horizons; pH 4.3.
A_p	3-8″	Dark yellowish brown (10 YR 3/4) fine sandy loam; very friable; massive in place but crushes down into very weak subangular blocks; many fine roots less than 5 mm in diameter penetrate this horizon. A weak platy structure has developed in the lower part; pH 4.6. Rapid permeability. Lower boundary sharp.
B_{22}	8-12″	Strong brown (7.5 YR 5/6-5/8); fine sandy loam; very friable; weak subangular blocky; roots are somewhat coarser (1 to 6 cm in diameter) than in overlying horizon; pH 4.5. This horizon appears slightly darker brown than horizon below but the difference is not noticeable on the color chart. Moderate permeability. Lower boundary not distinct.
B_{23}	12-20″	Strong brown (7.5 YR 5/6-5/8) to yellowish brown (10 YR 5/6) fine sandy loam; very friable; massive in place but crushes down into soft crumbs; pH 4.6. Moderate permeability.
D_1	20-26″	Yellowish brown (10 YR 5/6) loamy coarse sand; essentially structureless (single grain); pH 4.8. Moderate permeability.
D_2	26-33″	Yellowish brown (10 YR 5/6) fine sand; essentially structureless (single grain); pH 4.9. Moderately rapid permeability.
D_3	33-70″	Brown (10 YR 5/3) stratified coarse sand and fine gravels originating from the following rocks: sandstone, gneiss, schist, granite, and some Triassic shale; these gravelly sediments are very deep and have delta-like stratification; pH 4.9. Very rapid permeability.

Small and medium-sized roots are fairly evenly distributed throughout the solum; very few fine roots in sand and gravel substratum. Depth of solum varies in pit from 20 to 24 inches. About 60% of material in D is from crystalline rocks and 40% from Triassic rocks.

[1](43), p. 166.
[2](43), p. 167.
[3]Humus layer descriptions according to Lunt (30).
[4]Color determinations on moist soil (43).

In Connecticut, it is not unusual to find very thin A_{00}, A_0 and A_1 horizons in areas previously cultivated, probably 75 to 100 years or more ago (as estimated from present tree growth), and now in forest.

Figure 4. Typical land-use and topography of the Wethersfield. Much of the area is cleared and in crops. Forest vegetation is comprised mainly of oaks with some hickory, maple, birch, hemlock, and white pine and a sparse understory of shrubs and tree seedlings. This soil occurs predominantly on drumlins with long and gentle to occasionally steep slopes. Location — Day Hill, Windsor, Connecticut. September 22, 1953.

Since the first settlement in Connecticut in 1633 at Windsor in Hartford County, the land in some areas has been cleared, farmed, abandoned and new forest growth appeared, many places probably going through one or more complete cycles. The land best suited for farming, however, has generally remained in cultivation. The plow layer in the forested areas is discernible because of the darker color of the soil compared with the B. In many places, the A_p is easily discernible but in others, it is not so easily seen. In some forested areas, remains of former cultivated fields are evidenced by the remnants of hilled-up cultivated rows.

Wethersfield Silt Loam

Sample No. S48 Conn. 2-1-(1-8)

Location: Day Hill, Windsor, Connecticut. Coordinates on soil profile location map (Hartford N USGS quadrangle): No. 1; 0.8-D.7; 383.

Topography: Sampled near crest of drumlin on 7% southwesterly slope. The topography of surrounding area is hilly to rolling.

Vegetation: Mixed hardwoods (cut-over area) and conifers including black oak, white oak, red oak, shagbark hickory (*Carya ovata* (Mill) K. Koch), pignut hickory (*Carya glabra* (Mill) Sweet), red maple, gray birch (*Betula populifolia* Marsh), eastern hemlock, and white pine. Sparse shrub growth includes mountain laurel (*Kalmia latifolia* L.), low-bush blueberry, and greenbrier (*Smilax rotundifolia* L.).

Drainage: Well drained. Surface runoff medium to rapid. Very rapid to slow permeability.

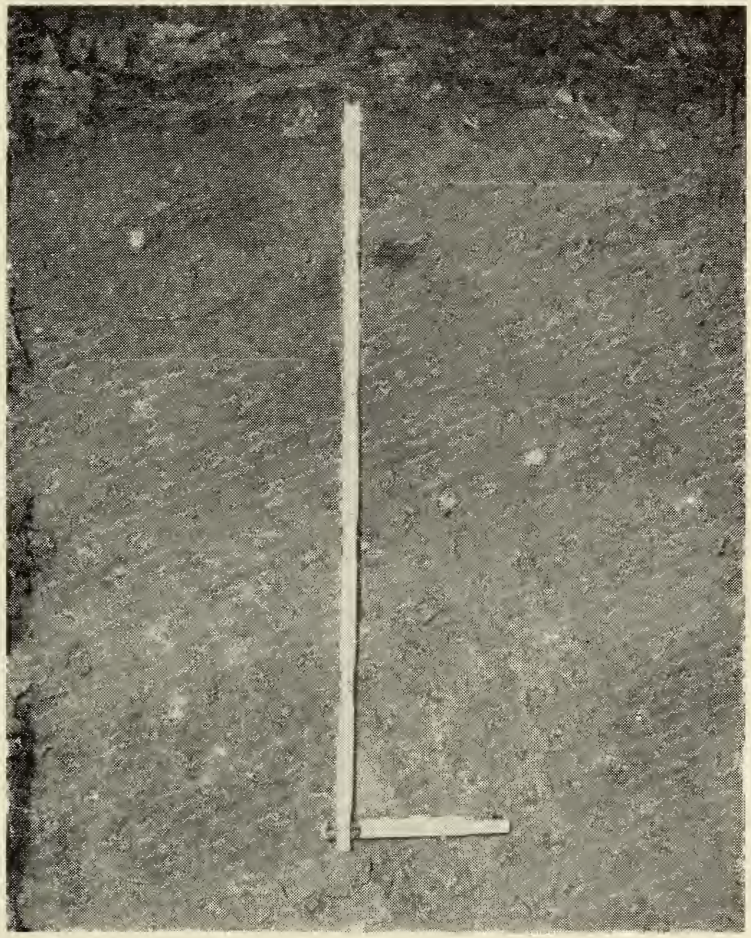

Figure 5. Profile of a Wethersfield silt loam in forested area in Figure 4. A thin layer of fresh leaves and partially decayed organic materials covers a thin A_1. The B horizon extends to 20 inches, becoming redder in color with depth, grading into the C_1. The C is distinctive in being a compact till with slow permeability compared with the firm consistence and moderately rapid permeability of the B. Roots are practically limited to the solum. A detailed description is given on pages 8 to 10.

Parent material: Unstratified glacial drift. Surface stones consist of red sandstone and siltstone and trap rock (dolerite or basalt) of Triassic age in about equal proportions. Rock fragments and stones throughout the profile are mainly sandstone and shale with some siltstone.

Use: Principally hardwood forest. No evidence of plow layer.

Soil Profile Description

Horizon	*Depth*	*Description*
		Thin duff mull.
A_0	1-0″	Very thin black organic matter layer; pH 4.4.
A_1	0-1″	Black (2.5 YR N2/) silt loam; very loose and friable when removed but firm in place; weak fine crumb structure which breaks up into granules 1 mm in diameter; pH 4.2.
B_1	1-4″	Dark reddish brown (2.5 YR 3/4) silt loam containing a few reddish-brown sandstone and shale fragments; loose subangular blocky structure grading into a weak platy structure in the lower part; firm in place, friable when removed; pH 4.4. Very rapid permeability.
B_2	4-13″	Reddish-brown (2.5 YR 4/4) silt loam; more firm and less friable than the B_1 horizon; weak platy structure; abundant sharp angular fragments of Triassic shale and siltstone; pH 4.4. Moderately rapid permeability.
B_3	13-20″	Reddish-brown (2.5 YR 4/4) silt loam; well developed platy structure; lenticular structural units are approximately 1 mm thick and 6 mm long; roots are very uniformly distributed to a depth of 20 inches but practically none are found in the compact C horizon below; pH 4.6. Moderate permeability.
C_{1m}	20-30″	Dark reddish brown (2.5 YR 3/4) silt loam. This is a very firm and compact till containing abundant fragments of reddish-brown shale and siltstone and a few fragments of dark-gray diabase, olive schist, and light-gray granite. This till breaks up into irregular prismatic blocks with the surface of the structural units coated with a dark varnish of MnO_2; root holes are coated with shiny, greasy-looking clay; pH 4.6. Moderate to slow permeability.
C_{2m}	30-39″	Dark reddish-brown (2.5 YR 3/4) silt loam; pH 4.6. Description is the same as for C_1 except for its slow permeability.
C_{3m}	39-50″	Dusky red (10 R 3/3) silt loam; pH 5.1. Description is the same as for C_1 except for its color and slow permeability.

Several pits were dug near the original pit at different times of the year (50). On April 15, 1953 a pit was dug into the C horizon when the soil was in a moist state. Water was found to ooze through the 13-20 inch horizon from the higher elevation into the pit. The south side of the pit was moist but no water oozed through into the pit. Upon contacting the hard compact till, there was a noticeable difference in the moisture content. It was relatively "dry" below the 20-inch level. After digging in the compact till, the water rapidly filled the pit up to 20 inches. On several other occasions it was noticed that water oozed from about the 20-inch depth in road cuts made through drumlins and drumlin-like hills composed of Triassic sandstone and shale.

EXPERIMENTAL PROCEDURE

Physical Methods[1]

The mechanical composition of the soil samples was determined gravimetrically by the sieving, decantation, and centrifugation method de-

[1]Grateful acknowledgment is made to D. B. Downs of this Station for assistance in sampling the soils and in making some of the physical analyses; and also to Jean Leclerc, formerly of this Station, who assisted in the mechanical analysis.

scribed by Jeffries and Jackson (27) after oxidation of the organic matter by 10% H_2O_2 and removal of free oxides by Jeffries' (26) magnesium-oxalate method. The medium sand, fine sands, very fine sand, and the silt fractions (Table 1) were then subjected to heavy liquid separation with *s*-tetrabromoethane (specific gravity = 2.95). The sizes separated are given in Table 2. (For the convenience of the reader Tables 2 to 21 are placed in the Appendix on pages 46 to 59.)

Table 1. Size Limits of Separates Used in Making Mechanical Analysis of Soils

Separate	Diameter
	mm
Gravel	>2
Sand	
Very coarse	2 — 1
Coarse	1 — 0.5
Medium	0.5 — 0.25
Fine, coarse fraction	0.25 — 0.175
Fine, fine fraction	0.175 — 0.105
Very fine	0.105 — 0.05
Silt	
Coarse	0.05 — 0.02
Medium	0.02 — 0.005
Fine	0.005 — 0.002
Clay	
Coarse	0.002 — 0.0002
Fine	<0.0002

Bulk density, porosity, permeability, penetration, and field moisture measurements were made as described below. The data obtained are reported in Table 3.

Brass cylinders of 250 cc capacity (2-7/8″ ID x 2-5/16″ long) were used to obtain soil cores of the profiles with a minimum of disturbance of soil structure according to the method of Swanson (45). The top and bottom of the core were carefully trimmed flush with the ends of the cylinder and weighed in the field for field moisture determinations. Filter paper (E and D No. 615, 15 cm) and cheese cloth, held in place with a rubber band, were used for covering the bottom of the core so that no soil would be lost in handling. The core was placed, covered end down, in an inverted pint ice cream carton lid and then covered with the carton. Placing the core on the lid facilitated removal later from the carton. Care was taken that the carton was not inverted at any time. In order to reduce vibration, the cores were transported to the laboratory on 3-inch thick soft foam rubber mats.

The number of times required to lift a 12-pound hammer 2 feet high on a shaft and let fall in order to drive a 3-5/16-inch diameter core sampler into the soil 3-3/8 inches are recorded as strokes (Table 3).

Penetrometer measurements were made with a plunger-type apparatus made by the Roto-Tiller Company (31). The upper end of the probe was 1-1/8 inches in diameter tapering to a 1/4-inch conical tip at the lower end. The depth of penetration into the soil made by raising the 3 pound 5 ounce metal plunger 36 inches high was recorded (Table 3). Bulk density and total porosity were determined by standard methods (2).

In making permeability determinations, the cores were taken as they came from the field and placed on ceramic plates. All cores from the same horizon were placed on one ceramic plate (46), each plate holding seven cores. The ceramic plates were contained in a galvanized sheet iron tank 5 inches high, 28 inches wide, and 56 inches long. The tank contained two compartments and each compartment held four ceramic plates. The tank was filled by means of a valve mechanism attached with a hose to tap water. The cores were covered with about 1/8 inch of water and saturated for 16 hours. This thin covering of water allowed relatively free movement of entrapped air from the soil. The tank was covered with a plastic sheet to minimize evaporation. The transparent plastic facilitated observation of the cores.

After the saturation period, the cores were weighed individually in their saturated condition before the tank was drained. After weighing, the cores were placed on a perforated lid. Twenty-mesh copper wire screens separated the lid and the core, allowing free movement of water. A 1-inch brass ring was fastened to the top of the cylinder with a 1-inch wide rubber band. A piece of filter paper (E and D No. 615, 7 cm) was placed on top of the core. Ring stands supported the soil core, perforated lid, and 1,000 ml Erlenmeyers used for water supply. The 1,000 ml Erlenmeyer, stoppered with a No. 9 2-hole rubber stopper, was filled to capacity, inverted quickly over the soil core, lowered until it was about 1/2 inch over the soil, and then clamped into place. Beakers of 1,000 ml capacity were placed below the ring stand for collecting the percolate. A small piece of filter paper was placed on the bottom of the beaker allowing easy detection of the first drop of water as it came through the soil core. The length of time for the water to percolate through the soil was noted and the following calculations were made:

one cm height of soil sampling cylinder = 41.66 cc volume

one inch height of soil sampling cylinder = $41.66 \times 2.54 = 105.8$ cc

or 106 cc volume of soil sampling cylinder equivalent to one inch height of cylinder

$$\text{ml percolate equivalent to one inch} = \frac{\text{cc percolate}}{106}$$

$$\text{percolation, in/hr} = \frac{\text{inches percolate}}{\text{percolate time}}$$

Permeability classes as described in the Soil Survey Manual (43) were used.

The capillary and noncapillary porosity of the samples were determined after obtaining their permeability. The method of Swanson

and Jacobson (46) was used with some modifications. The soil cores were placed on the ceramic plates, resaturated for 16 hours and weighed as described above, and then put under 60 cm tension for 24 hours. The tank was covered during the tension period with the plastic sheet to minimize evaporation.

Chemical Methods

The carbon content of each horizon was determined by wet combustion (40) and total nitrogen by the standard Kjeldahl method. Exchangeable H and cation exchange capacity were determined by leaching the soils with 0.5 N barium acetate according to Chandler's (7) method. Analysis of the exchangeable K and Na was made by the flame photometer technique as described by Toth and Prince (51) and exchangeable Ca and Mg by Peech's (38) method. The pH measurements were made potentiometrically, using the glass electrode in a 1:1 soil-water mixture as described by Cummings and Reed (11). The data are reported in Table 4.

The free oxides (oxides in solution after oxidation by 10% hydrogen peroxide and treatment with Jeffries' (26) magnesium-oxalic acid method) in these soils (Table 5) were determined as follows.[1]

The extraction and dehydration of SiO_2 was accomplished according to the standard silicate analysis procedure outlined by Scott (41). The final determination of the SiO_2 was performed by evaporation with hydrofluoric acid in platinum crucibles.

The free iron oxide was determined by a modified procedure of the cupferron (22, 29) method in which the ammonium salt of nitrosophenyl-hydroxylamine is used to precipitate the iron quantitatively. The extractant from the silica determination was diluted to 100 ml; 20 ml of concentrated hydrochloric acid were then added and the iron was precipitated (in ice-water bath) by the addition of Baudisch's reagent until a temporary flash of a white precipitate appeared. The iron precipitate was filtered and washed successively with cold 2 N hydrochloric acid, cold distilled water, and dilute cold ammonium hydroxide. The precipitate was slowly ignited to Fe_2O_3 in porcelain crucibles.

The free alumina was determined on the filtrate of the cupferron separation by direct precipitation in ammoniacal solution. Five g of ammonium chloride and 5 g of concentrated nitric acid were added to the filtrate. After boiling and cooling, 2 to 3 drops of 0.01% phenol red indicator were added and the aluminum precipitated by adding dilute ammonium hydroxide. The solution was heated to boiling, the aluminum precipitate filtered immediately, and washed with hot neutralized 2% ammonium chloride. The precipitate was redissolved with hot 1:1 hydrochloric acid and reprecipitated by repeating the above procedure. The precipitate was then ignited in a platinum crucible to a constant weight using the hottest flame of a Meker burner.

[1]Grateful acknowledgment is made to G. Talvenheimo, formerly of this Station, and now with the Houdry Process Corp., Marcus Hook, Pa. for designing the procedures and for determining the free oxides, the cation exchange capacity and the total potassium of the silt and clay fractions.

The free manganese dioxide was determined on the filtrate from the aluminum separation. After the addition of 20 ml of concentrated nitric acid, the filtrates were taken to dryness on the hot plate. This was followed by the addition of 15 ml of concentrated sulfuric acid and by volatilization as SO_3. The residue was next taken up in 100 ml of distilled water and 1 ml of 85% phosphoric acid and 0.3-0.5 g of sodium iodate added. The solution was boiled for 3 minutes, cooled, and diluted to 250 ml. The manganese was determined colorimetrically by comparison with standard manganese solutions. By means of a Lumetron colorimeter the per cent transmittancy was measured and plotted on semi-log graph paper. Transmittancy was measured at a wave-length of 530 millimicrons. The efficiency of recovery of the Fe_2O_3, Al_2O_3, and MnO determinations was obtained by subjecting known amounts of these substances to the same chemical treatments used for unknown samples. The recovery of the analytical methods employed was of 95 to 100% for Fe_2O_3 and 100% for Al_2O_3 and MnO.

Cation exchange capacity was determined on calcium-saturated fine silt, coarse and fine clay fractions. The data are given in Table 6. The method employed was a modification of the semi-micro leaching method used by Peech (38). The modification involved leaching the fractions with ammonium acetate and other leaching agents by employing fritted glass filters of medium porosity. This was necessary in view of the small samples available for analysis and because of the fineness of the particles. A Lumetron colorimeter and a 410 millimicron wave-length light source were used in the colorimetric comparisons. The accuracy of the method was checked by a determination of the cation exchange capacity of bentonite, illite, and vermiculite, giving the following values for standard clay minerals passing through a 300-mesh sieve:

Clay mineral	*m e/100 g*
Wyoming bentonite	80.0
Illite (Fithian)	30.0
Vermiculite (Webster)	152.0
Vermiculite (Var. Jefferisite)	145.6

The total potassium was determined on the sodium-saturated samples (30) remaining from the cation exchange capacity determinations. The analytical method employed was that of Smith (42), which utilizes calcium carbonate and ammonium chloride for the fusion of the samples. The extraction procedure was modified after one described by Gammon (18), using 400-600 ml of extractant instead of 300 ml. The K was determined by means of a flame photometer (Perkin Elmer No. 52A). The standard curves prepared for each set of samples were based on solutions containing 100 ppm lithium and 0.5 ppm sodium. The latter element was added in order to compensate for the sodium introduced during the cation exchange capacity determinations. The accuracy of the method was obtained by determining the K in duplicate samples of potassium chloride that had received the same treatment as the unknown. The effect of sodium was also determined by adding known quantities of sodium chloride to known amounts of potassium

chloride and analyzing for K. It was found that, in the absence of sodium, 100% of the potassium was recovered whereas the presence of large amounts (exceeding the quantities held as exchangeable ions) of sodium resulted in lowering the efficiency of recovery to 97%. The data are given in Table 7.

Mineralogical Methods

Minerals were identified with a petrographic microscope using standard descriptive mineralogical texts. The quantitative estimation of the various minerals was made on a basis of 250 mineral grains counted and identified from each slide (Tables 8-21). One slide for each size separate for each horizon was prepared.

The minerals of the clay and silt fractions were determined with a Philips X-ray diffractometer type 12021. The details of this instrument have been discussed by Buhler (5), Friedman (17), and Firth (14).

All patterns were obtained by scanning from 50°to 4° (2 θ) at a rate of 1° (2 θ) per minute using iron Kα radiation and a manganese filter. The slit system was set with the widest vertical slit at the X-ray tube portal (5 mm high) and the narrowest vertical slit (5 mm high) at the Geiger tube portal. This slit system allowed the strongest reflected

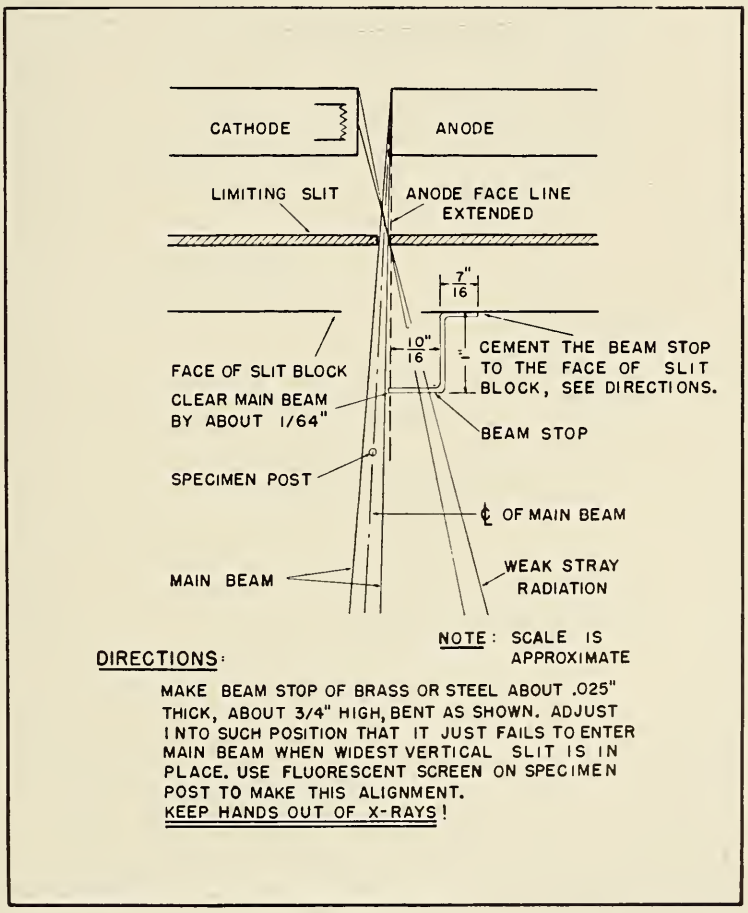
CATHODE
ANODE
LIMITING SLIT
ANODE FACE LINE EXTENDED
7" 16
10" 16
CEMENT THE BEAM STOP TO THE FACE OF SLIT BLOCK, SEE DIRECTIONS.
FACE OF SLIT BLOCK
CLEAR MAIN BEAM BY ABOUT 1/64"
BEAM STOP
SPECIMEN POST
℄ OF MAIN BEAM
MAIN BEAM
WEAK STRAY RADIATION
NOTE: SCALE IS APPROXIMATE
DIRECTIONS:
MAKE BEAM STOP OF BRASS OR STEEL ABOUT .025" THICK, ABOUT 3/4" HIGH, BENT AS SHOWN. ADJUST INTO SUCH POSITION THAT IT JUST FAILS TO ENTER MAIN BEAM WHEN WIDEST VERTICAL SLIT IS IN PLACE. USE FLUORESCENT SCREEN ON SPECIMEN POST TO MAKE THIS ALIGNMENT.
KEEP HANDS OUT OF X-RAYS!

Figure 6. Low-angle beam stop for Philips X-ray diffractometer type 12021.

rays to be recorded on the charts for semi-quantitative estimates of minerals by measuring the area under the peaks representing reflections characteristic of a mineral (usually the basal reflections). Techniques used for semi-quantitative estimation of clay minerals were essentially those developed by Talvenheimo and White (49).

Since the background was high at low scanning angles, due to stray radiations, a low-angle beam stop was designed to eliminate these interfering rays. Figure 6 gives the details of this beam stop which is designed for the type 12021 Philips X-ray diffractometer. High background obtained in the low-angle range with the X-ray diffractometer is due to stray radiations originating from the slit system and the interior walls in the rear of the X-ray tube housing. These rays emerge from the slit system at the wider angle than the primary beam itself and can be stopped before they reach the Geiger tube window. This is done by adjusting a steel shield between the specimen holder and the

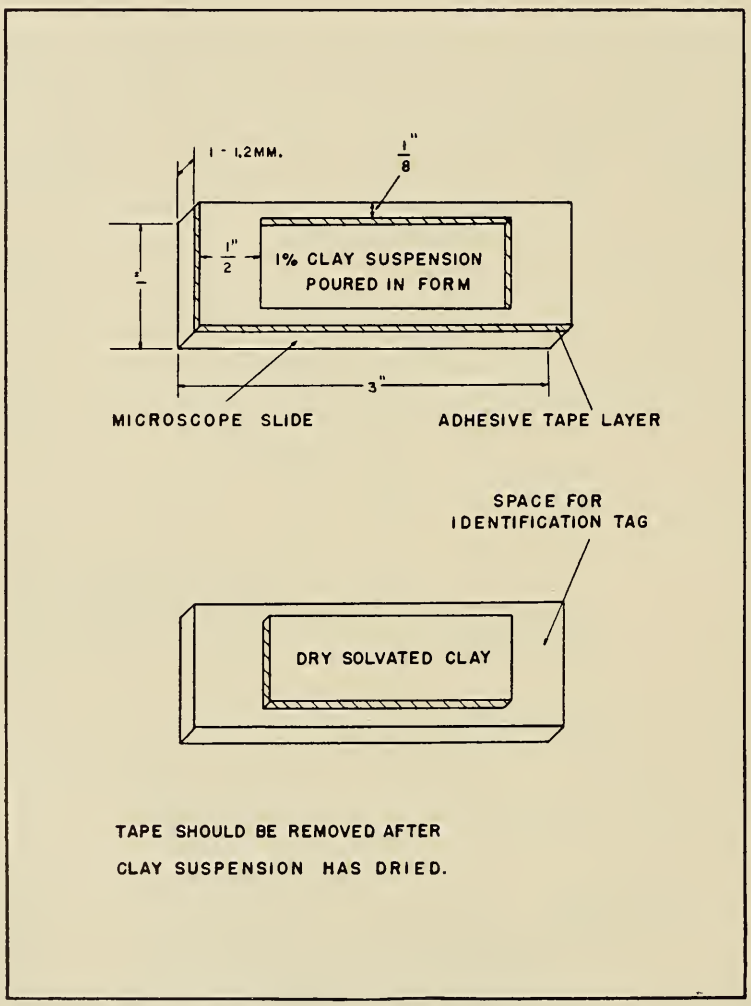

Figure 7. Apparatus and method for mounting clay samples for X-ray diffractometer.

X-ray tube slit system in a position such that only the primary X-ray beam is allowed to pass. It is very important, however, that the primary beam not touch the shield since more stray radiations and con-

tamination will occur, thereby defeating the purpose of the shield. Most clay minerals will cause high background at a low angle but this type of background is not reduced by the shield.

Several types of specimen mounts were tried for examining the clay fractions and the fine and medium silt fractions. Two types of mounts for powder samples, a steel one described by Christ *et al.* (9) and an aluminum one described by McCreary (35) were found suitable for silts and sands. For clays, however, they required too large a sample.

A simple mount was devised by the authors which was satisfactory for soil clays. This consisted of the usual 1 x 3-inch microslide on which a rectangular frame of adhesive tape was placed, the inside dimensions being 2 x 3/4 inches (Figure 7). The solvated clay suspensions described below were placed in the frame and dried in a vacuum desiccator (R.H. = 8%). When the clay suspension was dry, the tape was removed before placing the specimen on the diffractometer.

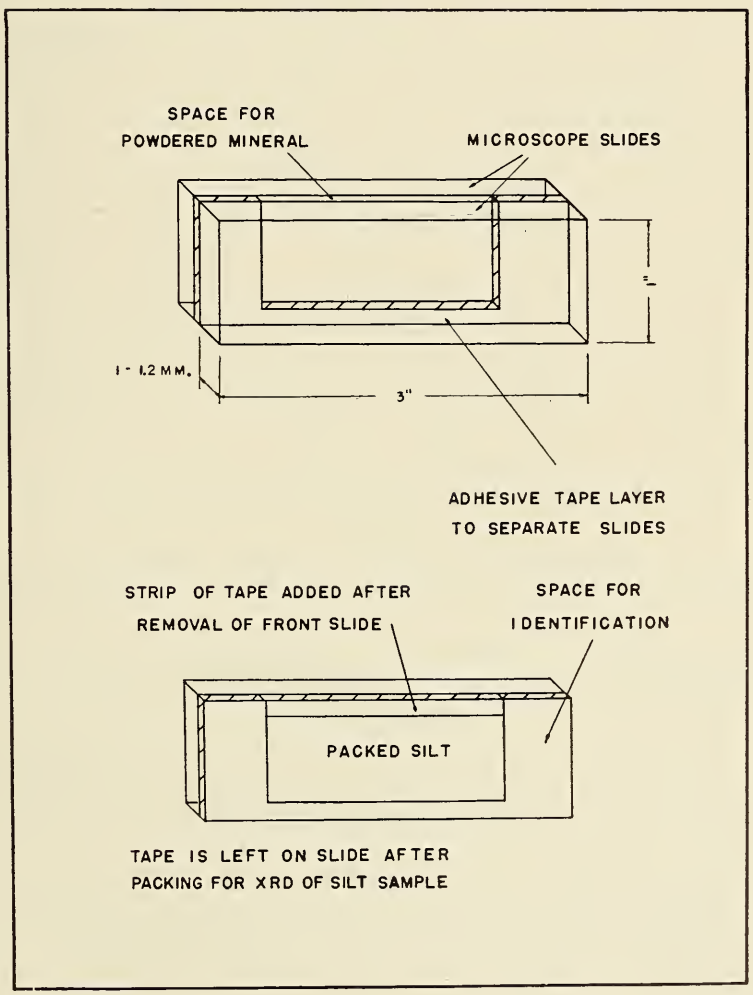

Figure 8. Apparatus and method for mounting silt samples for X-ray diffractometer.

For dry silt samples, the powder was packed gently between two microslides separated by a strip of adhesive tape, as illustrated in

Figure 8. One slide was then removed allowing exposure of a smooth flat surface to the primary X-ray beam.

For solvation, an aliquot containing an amount of clay estimated to weigh 10 mg was pipetted into a 100 ml centrifuge tube and calcium saturated by washing five times with calcium solutions (1st, 4th and 5th washings with 0.5 N $CaCl_2$ solution of pH 7; the 2nd and 3rd washings with N $CaAc_2$ solution of pH 7.7) to remove exchangeable H. These treatments (27) allow more complete calcium saturation of the clay and control the final pH so that it is practically neutral. The clay was then washed four times with methanol to free the solution of chlorides; the methanol concentration was increased stepwise from 60% in the first washing to absolute methanol in the last two.

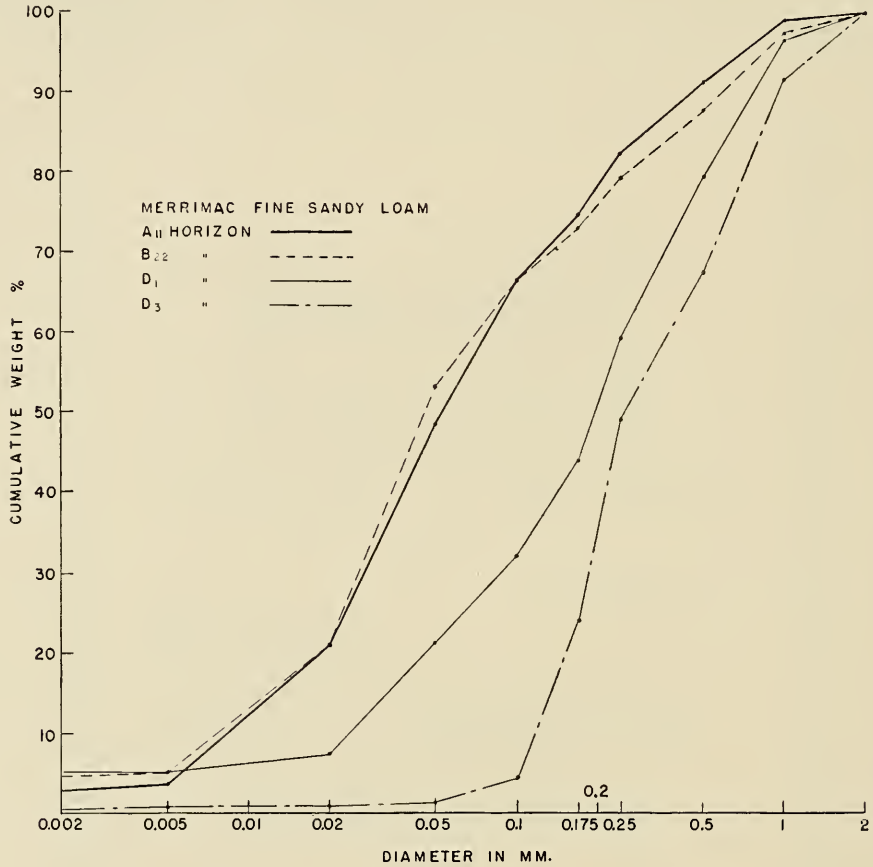

Figure 9. Cumulative-frequency curves (semi-logarithmic abscissa) of the soil separates of the A_{11}, B_{22}, D_1, and D_3 horizons of Merrimac fine sandy loam.

A 1% clay suspension was prepared by adding 1 ml of distilled water to the clay and 3 drops of ethylene glycol for solvation. The suspension was well mixed and dried in a vacuum desiccator as described above.

The interpretation of X-ray diffraction patterns of clay and silt minerals was made by comparison with Hanawalt's (20) cards giving standard patterns of pure minerals from measured *d* values and with the help of Brindley's (3) special tables of *d* spacings for clay minerals.

RESULTS

Particle Size Distribution Analysis

Figures 9 and 10 give cumulative-frequency curves of the mineral separates for selected horizons of the Merrimac and Wethersfield profiles. The data on the distribution of the separates in the horizons are given in Table 2.

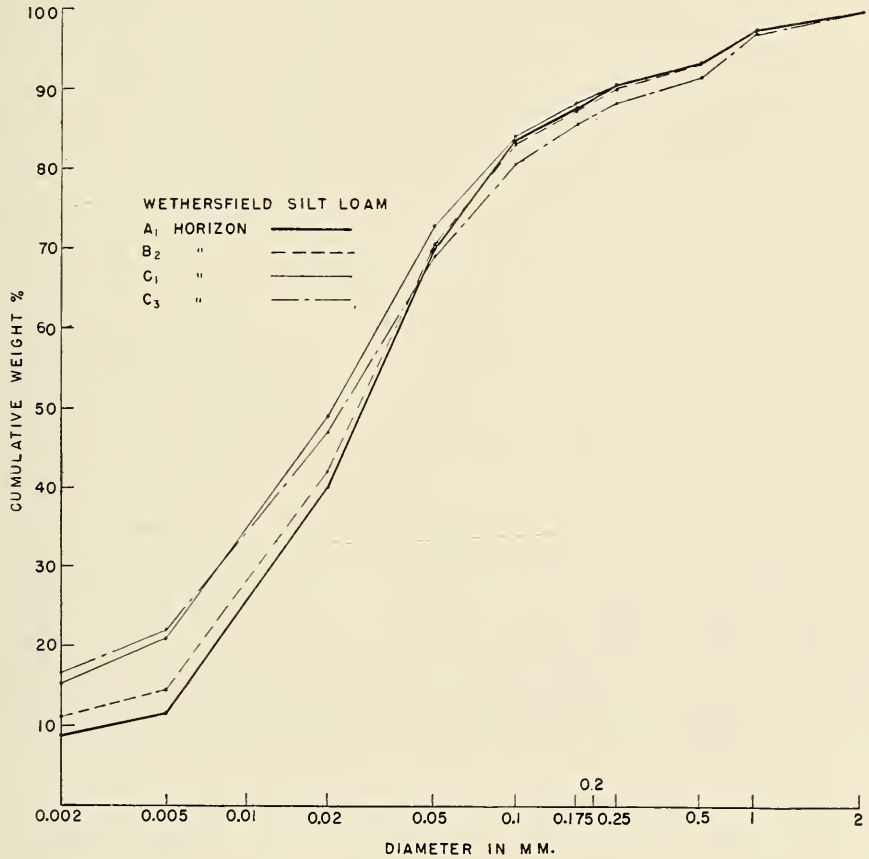

Figure 10. Cumulative-frequency curves (semi-logarithmic abscissa) of the soil separates of the A_1, B_2, C_1, and C_3 of Wethersfield silt loam.

Merrimac soils have an appreciable difference in size distribution of separates between the solum and the substratum. The curves for the solum indicate poor sorting and those of the substratum good sorting of materials. These data agree with another study (48) on the size distribution of the coarser particles in 10 Merrimac profiles from Hartford County. Clay and silt are almost absent in the substratum (Table 2). The maximum amount of clay (8.4%) occurs in the A_{12}. Coarse silt makes up about 25% of the solum, medium silt about 10-15% but fine silt less than 1%. Sands have an irregular distribution throughout the profile and make up as much as 98% of the substratum. Such a size distribution is common in stratified glaciofluvial sediments.

The Wethersfield, on the other hand, has a rather uniform texture throughout the profile. While the amounts of silt and clay increase

with depth, the total sands show little variation; the texture of all the horizons is a silt loam. The clay content of the C is decidedly higher than the A and B horizons; a decrease from 15.1% in the C_1

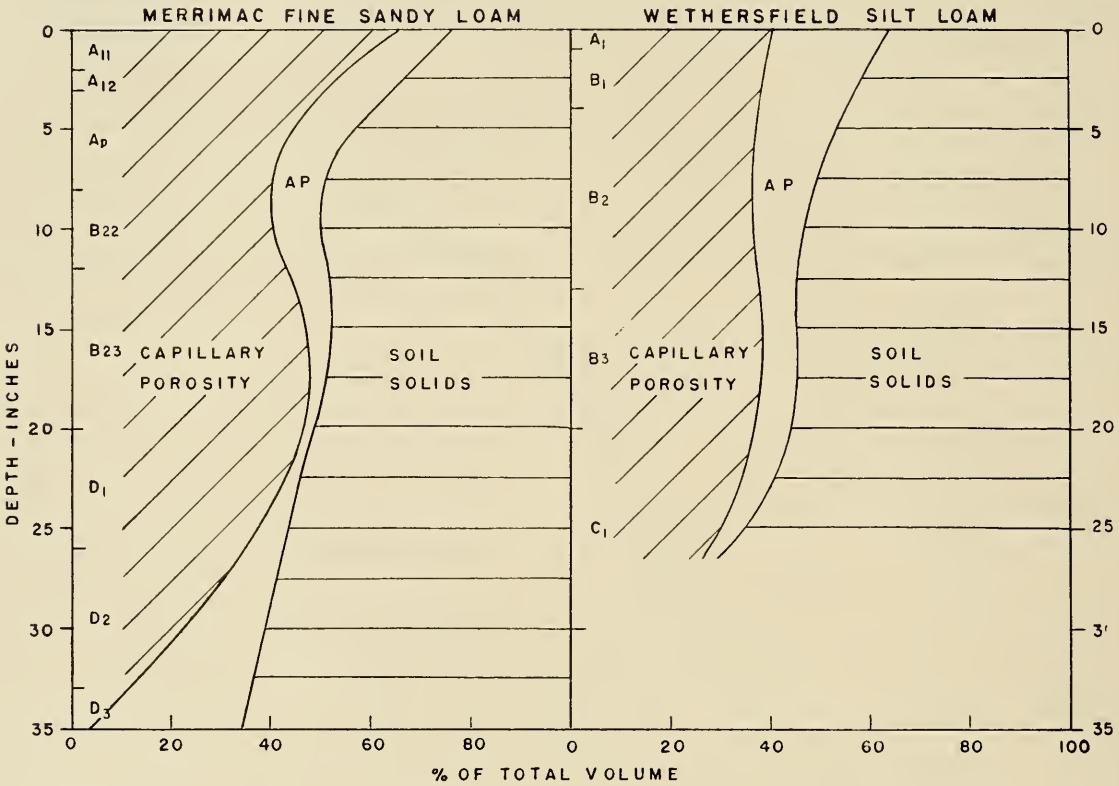

Figure 11. Capillary porosity, aeration porosity (AP), and soil solids by depth in the Merrimac and Wethersfield soils.

to 8.3% in the B_3 marks the horizons of greatest change. The silt content shows a gradual increase from the C_3 to the B_1 with a decrease for the A_1. The increase in silt and very fine sand particles in the B has been interpreted by Swanson *et al.* (47) as possibly being caused by eolian deposition.

Physical Relationships of the Soils

Information on the structural and permeability relationships of these two soils are given in Table 3 and in Figures 11, 12, and 13.

The two soils differ widely in their physical properties. Although the air porosity (non-capillary porosity) of the Wethersfield is greater in the surface horizons than in the Merrimac, the smaller air porosity in the substratum of the Wethersfield is the limiting factor in its permeability. The small differences in permeability in the sola between these two soils is not a reflection of their textural differences. One would have expected the Merrimac to have had a higher permeability. A logical reason for this difference is not readily apparent. In contrast to the fine textured Wethersfield, the sandy, gravelly texture of the Merrimac in the substratum offers little impedence to water move-

ment. Bulk density and the force (strokes) required to drive the core samples into the soil further point out the compact, massive nature of the Wethersfield.

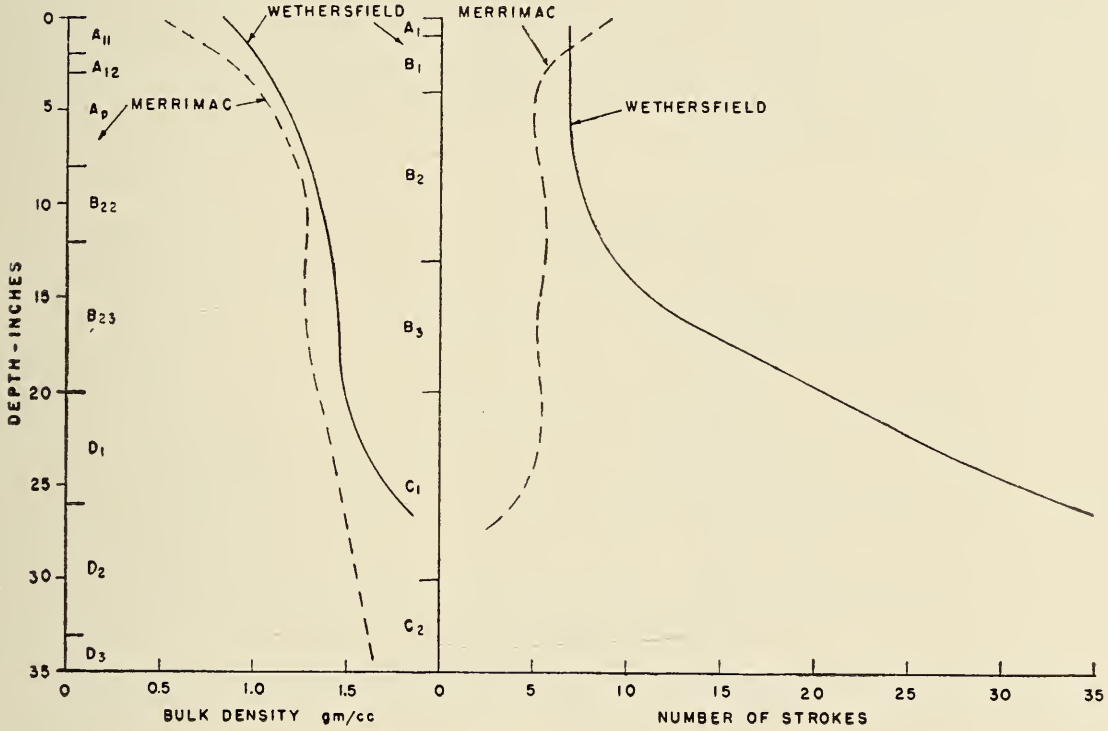

Figure 12. Bulk density and strokes required to drive a 3-5/16 inch diameter core sampler 3-3/8 inches into soil for the Merrimac and Wethersfield soils.

Chemical Analyses

Carbon and Nitrogen

The carbon and nitrogen and C/N ratios are given in Table 4. Both elements decrease rapidly with depth. The C/N distribution is about the same in both profiles, but the minimum value occurs at a shallower depth in Merrimac (3-8 inches) than in Wethersfield soils (13-20 inches).

In the Merrimac, the C/N ratio decreases from a value of 25.4 (A_{11} horizon) to 15.8 (A_p horizon) and then increases with depth rather rapidly. This may be accounted for by residual effects of the former plow layer. The lower C/N ratio suggests that previous cultivation in the A_p oxidized the organic matter to a point lower than in the underlying B_{22}. Under subsequent forested conditions leaf fall added to the organic matter regime of the A_{11} and A_{12}, increasing their C/N ratio.

In the Wethersfield profile the C/N ratio decreases with depth from a value of 23.1 in the A_1 to 6.0 in the B_3 horizon, then it rises in the C_1 and decreases again. The carbon in the substratum is probably derived from reduced carbonates.

Cation Exchange

In the Wethersfield the cation exchange capacity increases or decreases with clay and organic matter content. In the A_0 horizon with high organic matter the exchange capacity is 50 m e, decreasing to 4.3 m e in the B_3 which has the lowest clay content of 8.3%, but in the C_3 it increases to 10.6 m e with an increase in clay to 16.5% (Tables 2 and 4). A decrease in acidity in the C_3 accounts, in part, for the increased bases. Exchangeable H, however, decreases with depth as in the Merrimac profile.

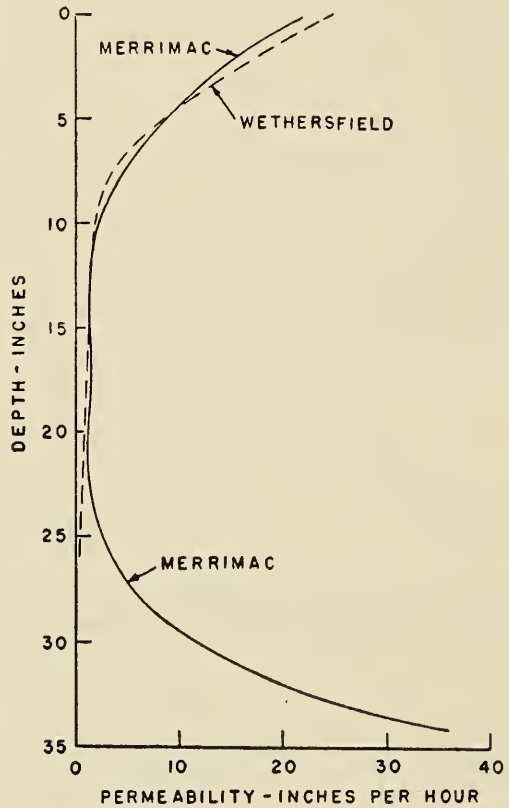

Figure 13. Permeability of the Merrimac and Wethersfield profiles.

The cation exchange capacity of the Merrimac decreases from 26 in the A_{11} to 0.8 m e in the D_2 horizon.

A comparison is made of the values of the cation exchange capacity for non-fractionated soils (Table 4) with those of the separate silt and clay fractions (Table 6, Figures 14 and 15). For both profiles the cation exchange capacities of the silt and clay fractions have patterns somewhat similar to those of the non-fractionated soils. The relatively high exchange capacities for the silt may be attributed to vermiculite and possibly to incomplete dispersion. The cation exchange capacities of the clay fractions are relatively high compared to those of the non-fractionated soil. This is accounted for by the relatively low content of clay in both soils (Table 2) causing a considerable dilution of the clay. The increase in exchange capacity with decreasing particle size is evident for all horizons of both profiles (Table 6, Figures 9, 10, 14 and 15).

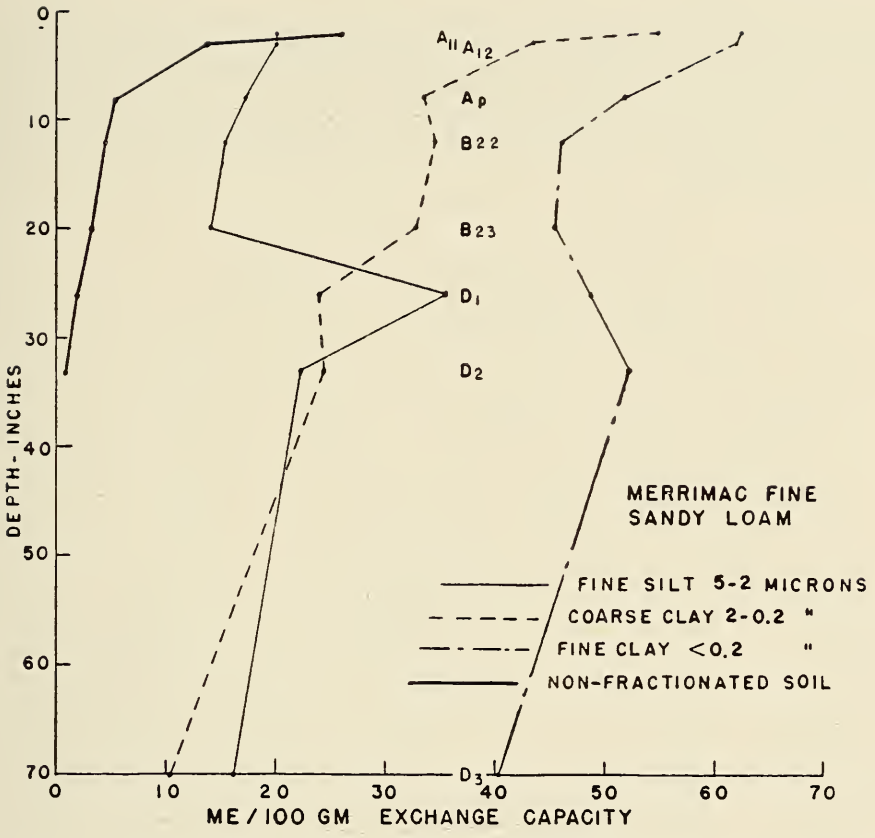

Figure 14. Variations in cation exchange capacity for the non-fractionated soil and for selected silt and clay fractions of the Merrimac soil.

Free Oxides

The horizon of maximum total oxides in the Merrimac is the B_{22} and for the Wethersfield the B_1 (Table 5, Figures 16, 17 and 18). Free oxides decreased appreciably below 20 inches for the Merrimac and below 4 inches for the Wethersfield. Morphologically, both soils have B horizons extending to 20 inches. Aluminum and iron oxides are present in almost the same quantities in both soils, except in the A_1 and B_1 horizons of the Wethersfield soil where the aluminum is distinctly higher.

Manganese oxides are negligible in the Merrimac but appear rather important in the Wethersfield. Manganese oxides have a tendency to accumulate in the A of Wethersfield soils, but there is evidence of some leaching in gravelly deposits adjacent to Wethersfield soils near drumlins. The pebbles or gravels are usually found coated with "desert varnish" or coatings of manganese and iron oxide. Observations and analyses by Ellis (13) in Africa indicate that in tropical soils the manganese along with titanium accumulates in the form of concretions on the surface rather than in the subsoil.

Mineralogical Analyses[1]

A quantitative study of the resistant minerals in soils provides a

[1]Grateful acknowledgment is made to J. W. Clarke, formerly of this Station and now at Vanderbilt University, for the identification and counting of the minerals.

criterion for identifying soil parent materials and for estimating degree of weathering. Certain minerals decompose slowly under a warm humid environment. Their quantitative variation in the profile gives information on the maturity of the soil. The data (Tables 8-21, Figure 19) reported pertain to the varieties and relative proportions of light and heavy minerals.

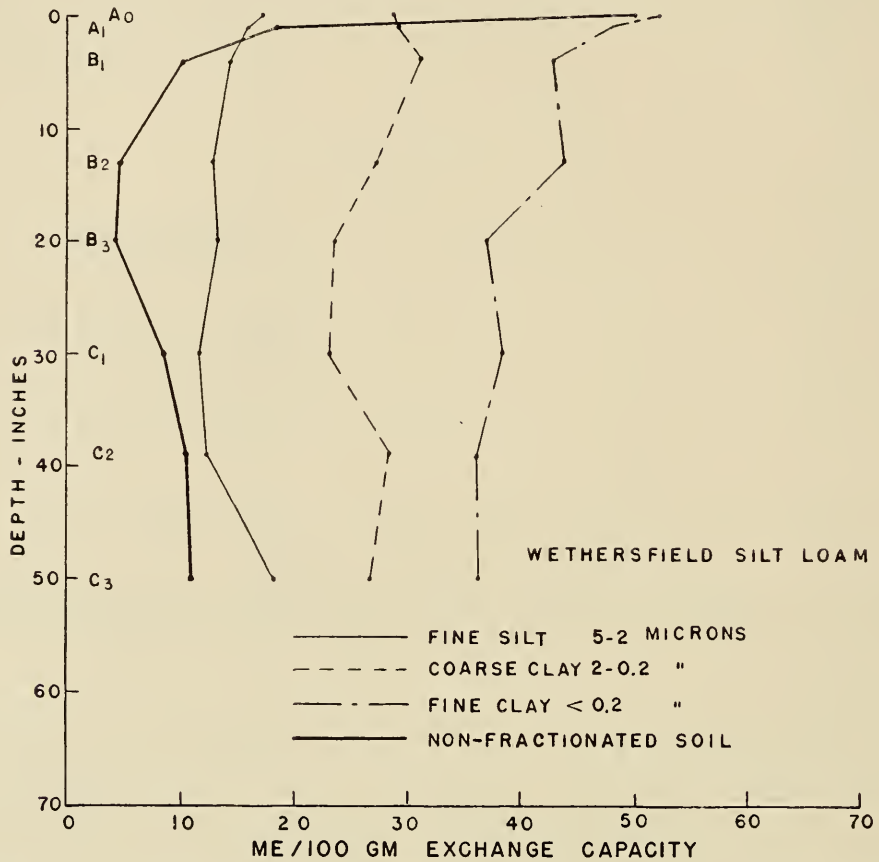

Figure 15. Variations in cation exchange capacity for the non-fractionated soil and for selected silt and clays of the Wethersfield soil.

Heavy Minerals in the Merrimac and Wethersfield

A gradual increase in heavy minerals to the D_1 occurs in the Merrimac (Table 8, Figure 19). At the D_2 the heavy minerals increase abruptly, then decrease considerably in the D_3, indicating a discontinuity caused by a different depositional environment. One characteristic common to both profiles is the slightly lower content of heavy minerals in the A_{12} horizon for the Merrimac and in the A_1 for the Wethersfield soil. The most striking difference between the two profiles is the much higher content of heavy minerals in the Merrimac.

In the Wethersfield, heavy minerals decrease gradually with depth; this is true for all size fractions. Figure 19 indicates a tendency for heavy minerals to reach a constant concentration with increasing depth in the substratum. In contrast, heavy minerals in the Merrimac increase in the (D_2) and for only the very fine sand and coarse silt fractions.

Colby (10) reported no significant variations in the mineralogical composition of soils in Massachusetts.

Additional information on the occurrence of heavy minerals in the Merrimac and Wethersfield soils is contained in the Appendix on pages 42 to 45.

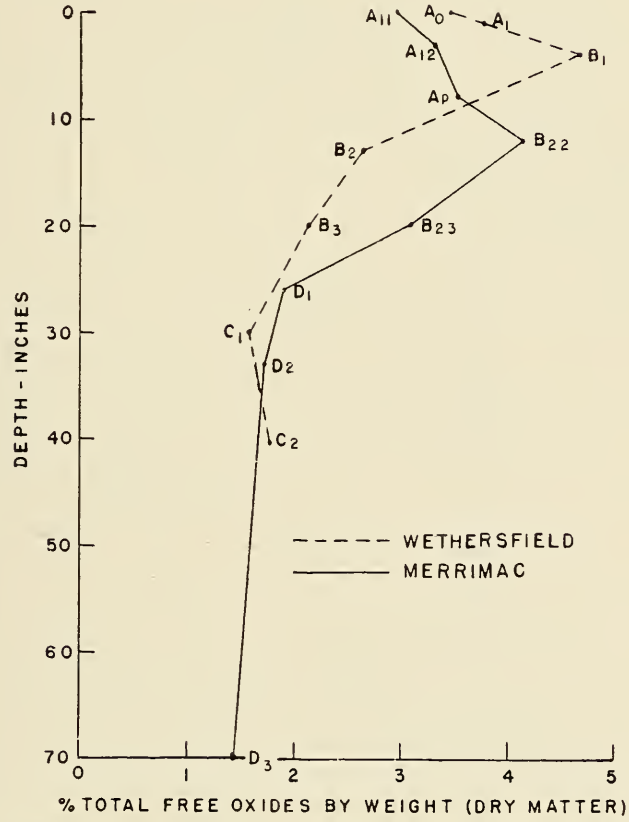

Figure 16. Distribution of the total free oxides (SiO_2, Fe_2O_3, Al_2O_3, MnO) in Merrimac and Wethersfield profiles.

Light Minerals in the Wethersfield

The light minerals were identified and examined in all horizons but no grain counts were made.

Quartz grains were very angular and had abundant inclusions of iron oxide and in some cases elongated subparallel rows and chains of black specks. Orthoclase is rare. Microcline is the predominant potassium feldspar. Feldspar grains show much more rounding than quartz.

Plagioclase is mostly sodic plagioclase and is not abundant.

Muscovite is rare in the coarse fraction of the soil but is relatively abundant in the silt.

Biotite shows all degrees of alteration, and most of it is found in the light mineral fraction.

Light Minerals in the Merrimac

An outstanding feature of the light minerals (Table 21) is the high ratio of microcline to orthoclase regardless of particle size and profile

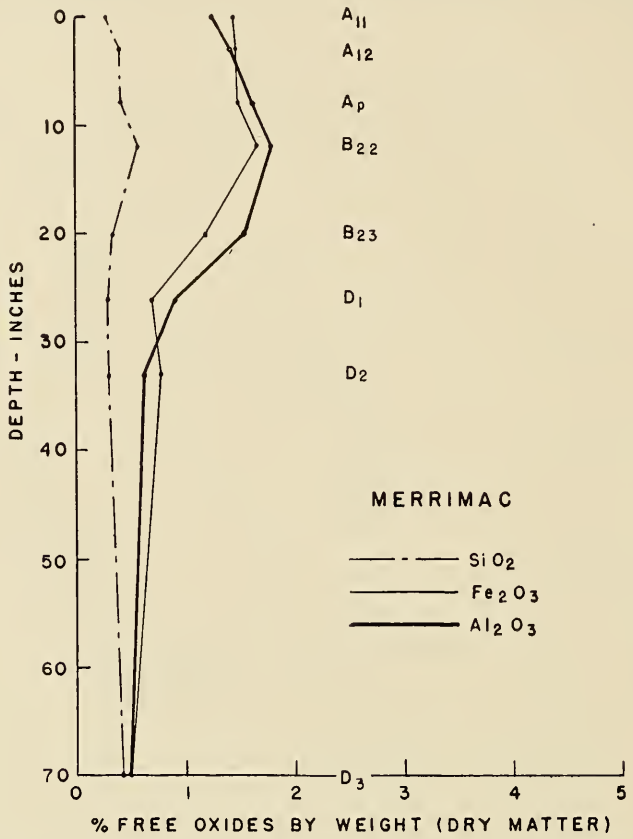

Figure 17. Distribution of free SiO_2, Fe_2O_3, and Al_2O_3 in the Merrimac profile.

depth. Microcline is more resistant to weathering than orthoclase, but in this case the parent rocks are low in orthoclase, as Krynine (28) points out. Other light minerals are quartz, which is predominant, and muscovite and biotite, which are present in all samples of this soil.

Quartz comprises 70 to 90% of the three coarser sands, decreasing in amount with decreasing particle size to make 60 to 70% in the three finer fractions. Orthoclase decreases with depth and also is somewhat less abundant in the coarser particle sizes. Microcline, biotite and muscovite increase with decrease in particle size. Biotite increases with depth while microcline has a very irregular distribution in the profile. All these minerals are characteristic of the crystalline rocks found in the source area in the Eastern Uplands.

Clay Minerals

Wethersfield Silt Loam

Fine Clay. The approximate percentage of clay minerals occurring in the Wethersfield has been reported by Tamura and Swanson (50). Vermiculite, ranging from 30 to 45%, was the most predominant mineral

in the solum, and illite, with a concentration of 60%, was most abundant in the substratum. About 15 to 20% of interstratified montmorillonite-chlorite were present in the B_3 and C horizons. Small amounts (5%) of kaolin were found in the upper solum and about the same amount of chlorite in the B_2, B_3, and C_1. Five to 10% hematite was distributed throughout the profile. Quartz and feldspars were absent.

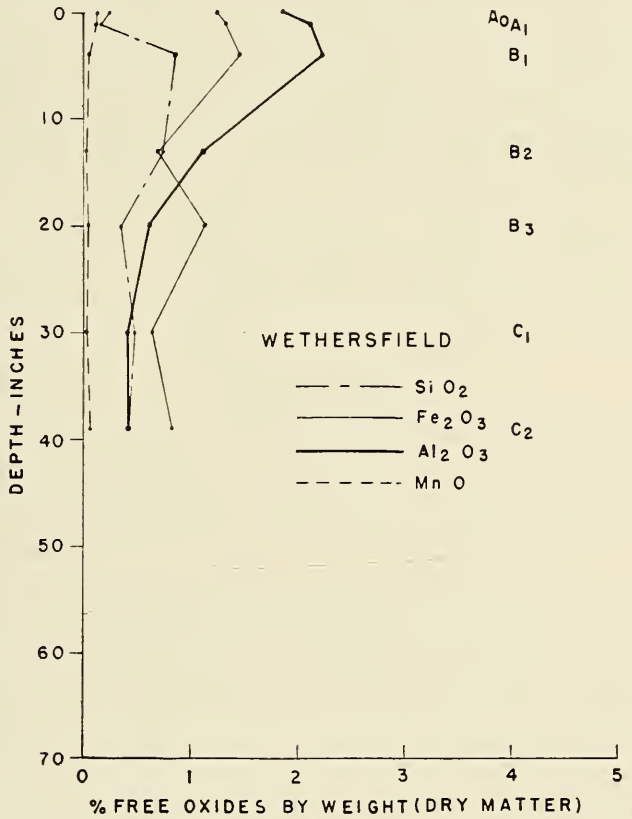

Figure 18. Distribution of free SiO_2, Fe_2O_3, Al_2O_3, and MnO in the Wethersfield profile.

It is evident that the weathering end product is vermiculite and that it is developing at the expense of illite (50). Some of the illite seems to be forming as the weathering product of muscovite and of biotite which are common primary minerals in Connecticut soils.

Coarse Clay. The distribution of clay minerals (50) in this fraction is similar to the fine clay except for about 15% more illite and 5 to 15% less vermiculite. Some evidence of quartz and feldspars was obtained.

Fine Silt. In the A and B horizons, illite in the fine silt was 5 to 10% greater than in the fine clay fraction; the amounts were about the same in the C (50). Vermiculite decreased about 5% in comparison with coarse clay. There was stronger evidence of quartz and feldspars, especially in the C_2 and C_3. Interstratified montmorillonite-chlorite and hematite were little changed. Kaolin was absent.

Medium Silt. The mineralogical composition of this fraction is homogeneous throughout the profile. In the light mineral fraction

(sp. gr. <2.95), from X-ray diffraction patterns, the minerals and their percentages are as follows: quartz 60, feldspar 20 and muscovite 20.

Merrimac Fine Sandy Loam

Fine Clay. Minerals of the fine clay are montmorillonite, chlorite, vermiculite, gibbsite and quartz. The A_0 horizon contains mostly organic matter, montmorillonite, and much amorphous material. Montmorillonite decreases with depth from about 75% in the A_{11} to about 5% in the D_1. Chlorite and vermiculite (14 A basal spacing)[1] increase in the profile from 10% in the A_{11} to about 50% in the B_{22}, then decrease rapidly to 5% in the B_{23} and D horizons. Gibbsite makes up about 10% and quartz about 5% of each horizon to a depth of 26 inches. From 26 to 70 inches the fine clay is made up mostly of amorphous material.

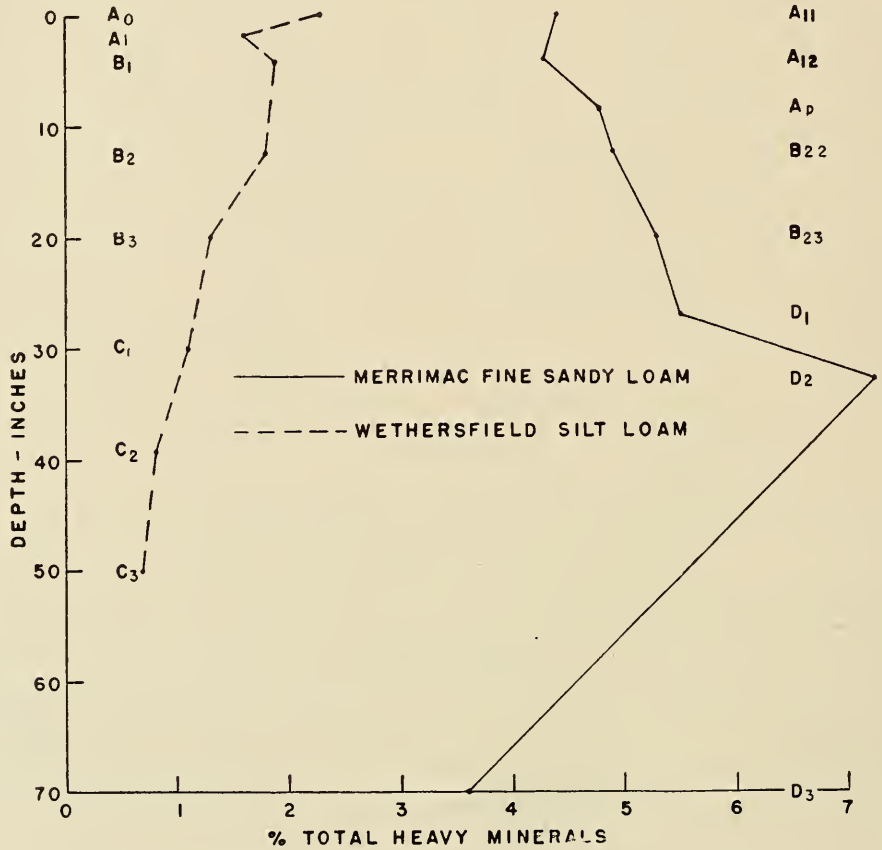

Figure 19. Total amount of heavy minerals in Merrimac and Wethersfield profiles.

Coarse Clay. Montmorillonite decreases from 70% in the A_0 to 5% in the A_p, then increases to 20% in the D_2 horizon. Chlorite and vermiculite are very low in the A_0 and A_{11} horizons indicating that they have weathered probably into montmorillonite; they are most abundant (70%) in the B_2 and make up 50% of the clay minerals in the rest of the profile. Illite increases with depth from 5% in the A_0 to about 25% in the D. Quartz fluctuates from one horizon to another as it usually does in fresh stratified materials; it ranges between 10 and

[1]Samples heated to 600° C indicated the presence of both vermiculite and chlorite but quantitative estimates of each were not made.

30%. Kaolinite and gibbsite are present to about 5 to 10% of the minerals of each horizon. Traces of feldspars are found in every horizon and in the D_2 they make up almost 20% of the minerals.

Fine Silt. It is interesting to find montmorillonite in the silt fraction of the A_0 and A_{11} horizons; it is suspected that it might exist as aggregates or floccules rather than as discreet particles. No montmorillonite was found in the B and D horizons. Chlorite and vermiculite increase from a trace in the A_0 to about 30% in the A_p and then decrease with depth. Muscovite is present as 10% of the minerals in all horizons. Quartz increases from 20% in the A_0 to 50% in the B_{22} and then decreases to about 5% in the D horizon. Feldspars are present (5%) in all horizons. A trace of kaolin is found in all horizons.

Medium Silt. Quartz, muscovite and feldspars are dominant in the light minerals. Quartz comprises 60% of the minerals to 26 inches, then drops abruptly to 20% in the D_2, and to 45% in the D_3 horizon. Muscovite and feldspars each make up about 20% of the light minerals.

DISCUSSION

Distribution of Separates in the Profile and Genetic Relationships

The frequency distribution curves in Figures 9 and 10 show a striking difference in particle-size distribution between the Merrimac and Wethersfield.

The Merrimac substratum is well-sorted, coarse textured, and almost free of silt and clay while the solum has a normal sorting curve. The very low content of clay in the B (Table 2) indicates that a short period of weathering has occurred after deposition. Such a profile has evidently formed on stratified materials from topset beds and partly from foreset beds. Such deposits were laid down as terraces or deltas in extensive areas of the Connecticut Valley. Apparently, the texture of the topset deposits, which form the parent materials of the solum, was fairly homogeneous. Soil-forming processes have produced the finer material in the B_{22} from the sands in the solum.

In contrast, the Wethersfield, as indicated by the similar shapes of the curves, has uniform material throughout the profile. The poor sorting of the Wethersfield materials is characteristic of glacial till. The B_2 is the horizon of maximum accumulation in the solum. The clay decreases in the B_3, increasing again in the C_1 (Table 2). Variations in the silts would not account for the clay distribution in the profile. In the B_3, the very fine sand increases slightly instead of decreasing. It is not normal for the B to have less clay than the C, at least not for Podzolic and Gray-Brown Podzolic soils. For example, recent studies of Gray-Brown Podzolic soils in New York (34) have shown that with increasing base status in the A horizon, the magnitude of the clay maximum in the B horizon increases. This explanation does not apply to the Wethersfield for the base status in the A is lower than in the B and C (Table 4).

A comparison of the textural variation of the B horizons suggests that Wethersfield is the older soil. A small accumulation of clay

has taken place in the B in both profiles (Table 2); this clay increase from the surface to the B_2 corresponds to a similar but greater increase in silt. The Wethersfield has a somewhat higher silt content and more than twice as much clay in its B which suggests that it is older than the Merrimac. Since the substratum of the Wethersfield is practically impervious as compared with the porous Merrimac (Table 3), the lower rate of clay translocation in the Wethersfield would suggest that it had to weather a longer time than the Merrimac to leach a comparable amount of clay.

In order to account for the clayey nature of the Wethersfield substratum two possibilities may be considered: (a) the clay was in the till originally, or (b) the clay in the subsoil is due to an old soil buried by a recent ice readvance.

The first case seems improbable. If the till was uniformly high in clay, on being deposited the soils developed from the till should have more clay in the B than in the C and the content of clay in the latter horizon should be fairly constant with depth. This is not the case.

The second explanation assumes that we have a polygenetic soil where the clay in the present substratum was acquired by pedogenic processes during a previous interglacial period. Subsequent glaciation apparently removed the surface horizons leaving a truncated profile. This is apparent in Wethersfield soils where the clay content increases with depth in the C horizon. The C_1 and C_2 horizons are, therefore, assumed to be part of the B horizon of an old truncated soil and the present B horizon is assumed to have developed in more recent surficial deposits brought in since the ice retreat. The fact that Wethersfield parent materials become calcareous with depth (47) suggests that this property is inherited from previous weathering and leaching.

Apparently, Wethersfield soils have been developed partly from till weathered from Triassic materials and partly from surficial fresh water and/or eolian sediments. These thin surficial deposits were subsequently mixed with underlying till by frost action, tree uprooting, and biological activity such as earthworm and rodent activity. While the solum was formed mostly on reworked materials, the substratum was left relatively undisturbed.

Field studies by the authors suggest that most of the drumlins in the Connecticut Valley have withstood at least one ice readvance. A large number of drumlins have been partially covered by glaciofluvial materials deposited consistently on the southeast side. The contacts between the drumlin till and the stratified gravelly materials are exposed in several gravel pits. The three most interesting exposures are located south of the Windsor water tower, on the southeast flank of Day Hill, Windsor, and on two large drumlins two miles northwest of Suffield.

During the last local ice readvance (Cary?), large blocks of till were removed from drumlins and other high knolls and deposited over varved clays laid down during the interglacial (Two Creeks?) period. Erratic till deposits over varved clays can be found in the vicinity of Cottage Grove in the town of Bloomfield. Flint (16) also refers to several other such localities where till was laid over varved clays.

During the ice retreat, large amounts of glaciofluvial terrace deposits were also deposited over the varved clays of Lake Hartford. It appears that at that time the highest drumlins may have been exposed above the ice and only a thin veneer of windblown material subsequently deposited on their surface. According to Flint (15) the majority of eolian deposits are east of the Connecticut River. Enfield and related soils have developed from these deposits.

The drumlins are the highest glacial topographic features in the Valley; they were the first deposits exposed to weathering when the ice retreated. The terrace materials on which Merrimac soils are formed probably were submerged while many drumlins, eskers and kames, being on higher ground, were exposed. The emergence and exposure of these terraces probably was gradual and extended over a period of time represented at least by the interval between the beginning of the Cary retreat and the post-Cary maximum. If the Two Creeks interval can be established in Connecticut, these soils may date from this time. The Two Creeks has been radiocarbon dated at 11,404 ± 350 years (16). Flint (16) has suggested that the Cary drift border passed south of Windsor in the vicinity of Middletown. Wind action apparently played an important role in reworking the surfaces in these relatively flat newly exposed areas before vegetative growth protected the surface. Field study shows that the well-sorted sands of the substratum are foreset deposits with delta-like stratification.

Mineralogical Composition, Soil Formation and Age Relationships

Heavy minerals generally increase or remain constant with depth in the Merrimac (Tables 15-20) but the opposite is observed in the Wethersfield (Tables 9-14). In the latter soil, minerals decreasing with depth are hornblende and epidote; the opaque minerals, magnetite and ilmenite, increase with depth. Although opaque minerals are more abundant in the Wethersfield they are decomposed; in the Merrimac they are still fresh and unaltered. This is accounted for by the fact that the opaque minerals in Wethersfield soils have been subjected to periods of weathering during Upper Triassic time (28) whereas those in Merrimac soils have been derived almost directly from the crystalline rocks of the Eastern Uplands. The more highly decomposed opaque minerals in the Wethersfield indicate that this soil is the older. The larger quantity of hornblende and epidote and the smaller amounts of opaque minerals in the Wethersfield solum in contrast to the substratum suggest that fresh minerals were incorporated in the solum. These fresh minerals are similar to those in the Merrimac.

The lower concentration of hornblende in the sand and silt fractions in the Wethersfield C indicates this material is inherited from an old buried soil. Further evidence of this is shown by the consistent amount of hornblende in these same fractions in all horizons in the Merrimac. The concentration of both epidote and garnet decreases appreciably in the silt fractions of the Wethersfield C but remains practically constant in all the Merrimac horizons. Zircon is present in larger amounts in the very fine sands and silt of the Wethersfield profile than in the

Merrimac. The opaque minerals also are two to three times more abundant in the Wethersfield coarser sands and from two to five times more abundant in the very fine sand and silt fractions. Because zircon and the opaques are the more resistant minerals, one would expect to find a higher concentration in an older soil. According to one weathering sequence of heavy minerals (25), the stability of the above minerals in decreasing order is zircon, garnet, ilmenite, magnetite, epidote, and hornblende.

Neither profile can be very old since the degree of weathering and change in concentration of resistant minerals such as zircon, tourmaline, staurolite, kyanite, brookite, rutile, garnet, and microcline are relatively small compared with soils formed under tropical conditions (25).

Textural variations in the Merrimac profile are accompanied by heavy mineral variations. The highest concentration of heavy minerals (Table 8) occurs in the coarse materials (D_2), the lowest in the fine materials (A_{11}, A_{12}, A_p and B_{22} horizons), and intermediate concentration in the intermediate materials (B_{23} and D_1 horizons). Such a distribution is normal because it is correlated directly with the rate of flow and velocity of the transporting agent. The interstratification of fine and coarse material can be accounted for by the dynamics involved in the formation of deposits resulting from glacier melting. As the volume of melt water decreases, its carrying capacity likewise decreases. The sediments become finer, and fewer heavy minerals are carried. Minor fluctuations in water flow cause minor variations of texture as expressed by stratification. This stratification has been masked by subsequent soil development. The mineral and textural layers, however, are still present because the relatively short period of soil formation has not obliterated this inherited mineral sorting.

The free oxide content of the B horizon (Table 5) is of the same order for both profiles in spite of the much lower permeability of the Wethersfield. This may be accounted for by the higher content of hornblende in the Merrimac. Because hornblende is one of the less stable soil minerals (25), more iron would be released on weathering in the Merrimac. This fact is interpreted in the light of the relative permeability (Table 3) of the soils. More time was required for the migration of an equivalent amount of oxides in the impermeable Wethersfield than in the porous Merrimac.

Apparently both soils originate from the same kinds of rocks, i.e. granite, gneiss and schist from the Eastern Uplands bordering the Connecticut Valley. According to Krynine (28) the Triassic sedimentary rocks of Connecticut originated from upland crystalline rocks. The drumlins on which Wethersfield soils are predominantly developed are derived primarily from Triassic sediments, especially shale and siltstone. The identical mineral suites of both soils (Tables 9-20) and their close field association gives evidence of a similar provenance.

It is difficult to determine whether the materials added to the Wethersfield solum are eolian or fresh water deposits. Wind action accomplished extensive superficial sorting as shown by several dunes scat-

tered throughout the higher terraces. Because fresh water and eolian environments existed, most likely both contributed in transporting the sediments. Because the eolian factor came last, it was probably responsible for the higher heavy mineral content of the finer sands and coarse silts of the A_0 and A_{11} horizons (Table 8). Mineral particles of this size range are most easily transported in suspension by wind, according to Chepil (8). Haseman and Marshall (21) also found that heavy minerals have a tendency to accumulate in size fractions susceptible to transportation by wind.

In a study of the mineralogical composition of some Podzol profiles in Michigan, Matelski and Turk (33) reported a greater decomposition of the heavy minerals in the B than in the A and C horizons. In the Wethersfield a greater alteration of heavy minerals was observed in the A_1, while in the Merrimac this alteration was greatest in the A_{12} (Figure 19). The present results are more in accordance with those of Richard and Chandler (39) who observed a higher degree of weathering in the A_2 horizons of Podzols rather than in the B and C. It seems, therefore, that leaching has caused the presence of a cryptogenetic A_2 horizon in both Wethersfield and Merrimac soils. It is possible that the more sandy soils were once thin or incipient Podzols. Cultivation or change of climatic and vegetational environment may have masked their original morphology, at least as far as an A_2 horizon is concerned.

From the observations made concerning the origin and modes of deposition of the parent materials of these two soils, two important conclusions may be drawn. First, one must be cautious in ascribing the substratum of a soil as its real parent material (C horizon). In the case of the Wethersfield, the substratum has only partially contributed to the parent material of the solum. In the case of the Merrimac, the gravelly substratum was not the parent material but rather unweathered foreset beds intermixed with finer topset beds. The solum of Merrimac soils has formed almost entirely from the topset beds of these delta deposits. Normally the coarse gravels underlying the sola of Merrimac soils should be assigned the term D horizon. However, it is not always easy to make such interpretations in the field.

Mineralogy of the Soil Clays

Clay mineral distribution in profiles also gives information on soil genesis. Abrupt changes in quantity or kind of clay minerals in the profile indicate critical genetic zones.

In the Merrimac, the concentration of montmorillonite, chlorite and vermiculite changes abruptly in the D_1 (20-26 inches). This point marks the transition zone between the solum and the gravelly substratum. Similarly for Wethersfield, a change in concentration of illite takes place in the lower B (13-20 inches) indicating the transition to the compact substratum. These changes in concentration of clay minerals in the Wethersfield offer further evidence that the substratum of this soil is a part of an old soil and that the substratum contributed only in part as parent material for the solum. The clay mineral dis-

tribution in both profiles indicates little clay movement into the B horizon suggesting these soils are youthful and immature.

Vermiculite appears to be the end product of soil-forming processes in this region. The minerals likely to weather into vermiculite in these soils are chlorite and illite. Such a trend has been pointed out previously by Jackson *et al.* (24) for Brown Podzolic and Gray-Brown Podzolic soils. Chlorite is present in some of the parent rocks (chlorite schists) of these soils and, when present, is abundant in the soil substrata.

The presence of illite as the predominant clay mineral of Podzolic and Brown Podzolic soils of New England was previously recognized by Haddock (19) and Holowaychuk (23). However, this does not necessarily mean that all of the illite is the end product of recent weathering. An appreciable quantity seems to have originated from pre-depositional weathering because the substratum of both profiles contains the largest quantity of illite. The advanced stage of decomposition of biotite indicates that part of the illite is a product of post-depositional weathering.

Although chlorite is present in the two profiles, it should not be expected in all Merrimac and Wethersfield soils of the Connecticut Valley. Only small amounts were found in the sands and silts in these two soils (Tables 9-21). Haddock (19) failed to find any in the clay fraction with the thermal methods he employed for the Merrimac profile. The presence of chlorite in the glaciofluvial materials and till would depend on the presence of chlorite schists in the source area.

Both kaolin and gibbsite are present in very low amounts and their presence is most likely due to pre-depositional weathering, because they have not increased in any horizon. There is doubt as to the presence of gibbsite in the Wethersfield (50).

The presence of hematite in the clay fraction of Wethersfield soils contributes to its red color. This hematite coats the sands and silts. However, reddish quartz and feldspar grains also contribute to this color. They occur abundantly as inclusions in rocks in the Wethersfield soil profile in comparison with the Merrimac. Some of these inclusions probably are hematite; undoubtedly as they are released from weathered grains of quartz and feldspars they become soil colloids. Quartz and feldspar grains in the Merrimac are clear and free of the red inclusions and coatings found in Triassic sediments. Quartz has not been decomposed appreciably in Merrimac soils because small quantities of it are still present in the fine clay fraction. In contrast, Wethersfield soils have no quartz in the fine clay fraction.

Haddock (19) found some goethite in Merrimac soils, but only in small quantities. If goethite was present in the samples analyzed in this study, the goethite most likely was reduced and destroyed when the iron oxides were removed. Biotite was found to be highly weathered in some samples. According to Walker (52) there should be some goethite present as a result of this alteration. Treatment for iron oxide removal also destroyed some of the hematite and montmorillonite.

In general, the cation exchange capacity values for the coarse and fine clays (Table 6) follow the concentrations of vermiculite. The cation exchange capacity of fine silt is usually high and can only be accounted for by the vermiculite in the solum and interstratified montmorillonite-chlorite, especially in the Wethersfield (50).

Morphology and Classification

It is important that soils of like characteristics be recognized so that new information obtained in one locality may be readily used in another locality having similar soils. Similar soils may occur in adjacent states, or in various parts of the United States, and even in other parts of the world. Because the study of soils, in comparison with some other sciences, is relatively young, much needs to be learned about soil characteristics on a state, national and world-wide basis.

In soil management and conservation work, it is especially helpful to know which soils have similar characteristics as a basis for general planning and for specific recommendations. Soil classification must be based upon all important characteristics of soils and must show the relationship of these characteristics to each other to be useful for management purposes. Consideration of those characteristics which show that soils similar to those studied occur elsewhere in this country and in the world are discussed in this section.

This study has established that both soils are relatively young and immature but that the Wethersfield profile appears to have been weathered somewhat longer. In general, soils formed on terraces or outwash materials will be somewhat younger than those formed on drumlins or higher topographic sites. Most soils formed on glacial till in this area cannot be considered as true parent material in the sense that the underlying till has contributed all of the solum materials. Either fresh water and/or eolian sediments have been incorporated with the underlying weathered till.

It is difficult to determine exactly how much sedimentary material has been incorporated in the solum of Wethersfield soils. Therefore, the substratum should be tentatively designated as a C horizon. However, in the case of Merrimac soils, the gravelly substratum is definitely not the parent material of the solum developed above it, and it should be designated a D horizon (48).

In a previous publication (47), both the Merrimac and Wethersfield were considered as members of the Brown Podzolic great soil group. According to criteria established for the Brown Podzolic soils (32, 47), the Merrimac may be considered as a member of this great soil group. However, recent introduction of concepts relative to criteria used for some great soil groups recognized in parts of Europe suggests that the Wethersfield should not be classed as a Brown Podzolic. Swanson *et al.* (47) in the earlier publication above suggested that the Wethersfield might be thought of as a minimal Gray-Brown Podzolic. The B_1 may be a weakly expressed A_2 such as characterizes the Gray-Brown Podzolic soils. The suggestion of a weak platy structure in addition to a lighter color in the B_1 in some profiles added weight to this hypothesis.

In parts of Europe, a great soil group known as Brown Earths of low base status ("Sol Brun Acide") has been recognized. Some major criteria[1] used in establishing this great soil group in the United States include a low base saturation compared with the 60%+ usually found in the Gray-Brown Podzolic, especially in the B; the texture is essentially constant in the A and B while the Gray-Brown Podzolic has a distinct textural B. Apparently, the Brown Earths differ from the Gray-Brown Podzolic soils in their base saturation, and in having a structural B instead of a distinct textural B. Also clay coatings are found on the blocky structural units of the latter but not in the former soil.

The Brown Podzolic soils differ chiefly in being friable throughout the profile with only faintly developed structure in the B. In morphology, the strongest colors in the Brown Podzolic are directly below the A_1 or A_p, while in the Brown Earths, the color may be uniform in the A_2 and B, or the B has a stronger color than the A_2. In other words, the color transition between the A and B in the Brown Earths is gradual while in the Brown Podzolic this transition is more abrupt. The base status of these two groups is roughly comparable.

Apparently, the Wethersfield is more nearly like the Brown Earths of low base status than either the Brown Podzolic or Gray-Brown Podzolic. Consideration, however, needs to be given to the importance of the weak platy structure occurring in the B, to the compact nature of the C horizon to depths of 15 feet or more, to the high manganese content throughout the profile, and to the general increase in calcareousness with increase in profile depth. Because the criteria for identifying fragipans have not been clearly and firmly established, one can only conjecture as to the name to be assigned to the compact horizons in the Wethersfield.

Further field and laboratory study needs to be done to establish conclusively to which great soil group to assign the Wethersfield.

Soil Fertility and Soil Management Aspects

Several fertility relationships can be derived from the mineralogical composition of these soils. The formation of vermiculite as a weathering product is important in contributing to a favorable cation exchange capacity. Apparently, illite is the primary source of potassium since orthoclase is rare and biotite is present only in moderate quantities (Table 21). Muscovite and microcline, which also are sources of potash, are present in appreciable quantities (especially in the finer fractions) but they are very resistant to decomposition.

The gradual weathering of several varieties of calcium-bearing minerals, especially hornblende, epidote, and zoisite, has been responsible for the growth of a good natural forest stand but this calcium release was not sufficient to prevent these soils from becoming acid. The potential supply of calcium, magnesium, and potassium is good but the actual rate of release of these elements is low. Boron and phosphorus seem

[1]Information kindly supplied by G. D. Smith, Soil Conservation Service, Washington, D.C.

to be critical elements in that tourmaline and apatite are present in extremely small quantities. Tourmaline ranged from about 1 to 5% of the heavy minerals; the higher amounts increase generally in the finer fractions. Apatite is absent in all horizons of the Merrimac except for 1 to 2% in the lowest horizon. In the Wethersfield, as much as 5 to 6% occurred in the heavy minerals of C_2 and C_3.

The Wethersfield is not considered a good soil for producing highest quality tobacco (1). In comparison with the Merrimac, it is not as well aerated and well drained. The coarser-textured soils are preferred to the finer-textured ones. The data on free MnO in Table 5 suggest another reason why high quality tobacco cannot be produced on Wethersfield soils. The MnO content in the Wethersfield solum ranges from 0.02 in the B_2 to 0.13% in the A_1 compared with 0.01% in the Merrimac. The profile description states that MnO coats the blocky structural units in the Wethersfield C_1 but none is found in the Merrimac. Anderson (1) states that below pH 4.5, the manganese becomes soluble and is taken up by the crop. Because tobacco-producing soils are kept at a pH of 5.0 to 5.6 for preventing the development of black root rot, many soils undoubtedly become acid enough to favor the formation of soluble manganese. In 1953, soil quick test data at the Tobacco Laboratory[1] at Windsor showed that 45% of the soils tested ranged between 4.0 and 5.0 pH. Because the Wethersfield is less permeable than the Merrimac (Table 3), soluble manganese compounds would accumulate less in the porous Merrimac. Soluble manganese is toxic to the tobacco plant, producing pale, stunted leaves. Cured leaves are of inferior quality and the presence of manganese compounds in the leaf gives an objectionable reddish-brown color to the ash. It is apparent that Merrimac soils with their lower content of MnO and higher permeability are more suitable for producing high quality tobacco than the Wethersfield.

The slow permeability of the Wethersfield substratum (Table 3) is an important factor contributing to the accelerated erosion[2] occurring on these soils. These soils occupy A (0-3%), B (3-8%), C (8-15%), D (15-25%), E (25-35%), and F (35%+) slopes. Erosion conditions vary from none or slight to severe. Cultivated areas on slopes above 4 or 5% are subject to moderate or severe erosion unless some provision is made for control of surface runoff. In the Hartford County survey, class 1 erosion is mapped on all the slopes, especially where the soil has been protected from erosion by the employment of land use practices such as pasture and forest cover. Class 2 (moderate) erosion is

[1]Unpublished data.

[2]Because the general concepts used in mapping erosion in Hartford County are not published, they are stated for the information of the reader.

Class 1 erosion is used to indicate areas where little or no significant water or wind erosion has occurred. Few or no special soil management measures are necessary as the result of past or existing erosion.

In class 2, erosion has developed to the degree that the productivity of the land is threatened or has been moderately reduced. Immediate attention is generally necessary to prevent further erosion, especially under poor soil management practices.

In class 3, erosion has developed to the degree that the productivity of the land has been materially reduced and hazards or limitations to the use of the land may have been created. Adequate erosion control measures and good land use practices are essential if further soil loss is to be prevented, except where good soil management and conservation practices are presently employed.

mapped on all the slopes but principally on the B, C, D, and E slopes while class 3 (severe) erosion is mapped only on the C and D slopes.

Because the Merrimac soils have moderate to very rapid internal drainage (Table 3) and their surface runoff is slow to very slow, erosion by water is not the problem that it is on the Wethersfield. Class 1 erosion is mapped on all the slopes. This soil occurs most extensively on A slopes but small areas are found on B and C slopes. The soils on the latter slopes usually occur on terrace margins and are largely in forests. Detailed descriptions and physical data on 10 Merrimac profiles are given elsewhere (48).

SUMMARY

A study was made of the morphology, mineralogy and genesis of the Merrimac fine sandy loam and the Wethersfield silt loam, two soils occurring in the Connecticut River Valley.

A special method was developed for mounting clay and silt size minerals for analysis with an X-ray diffractometer. A special beam stop was designed to reduce background effect by stray radiation from small 2 θ angles.

The mineral suites of both soils are very similar, although the Merrimac is derived from granite, gneiss, and schist from the Eastern Uplands and the Wethersfield from Triassic sedimentary rocks. This is explained by the fact that Triassic sediments of the Connecticut Valley also originated from upland rocks.

Heavy minerals are present in the following order of decreasing abundance: hornblende, epidote, opaques (principally magnetite and ilmenite), garnet, staurolite, zoisite, andalusite, kyanite, chlorite, sillimanite, tourmaline, zircon, brookite, rutile, orthopyroxenes, clinopyroxenes, and apatite. Most of the minerals in the Wethersfield are fresh and unaltered except for the opaques, which are more decomposed. This was accounted for by longer exposure of the latter soils to weathering.

Light minerals (sp. gr. <2.95) were found in the following order of decreasing abundance: quartz, microcline, muscovite, biotite, orthoclase, chlorite, and plagioclase. The low content of orthoclase is due to inheritance from the parent rocks rather than to long periods of weathering.

Field studies show that the glacial till of drumlins on which Wethersfield soils have developed have withstood an ice readvance. Subsequently, a veneer of fresh water and/or eolian deposits was laid over and mixed superficially with the till. The Wethersfield solum has developed from this surficial admixture, and the compact substratum consists of relatively undisturbed till.

Merrimac soils have developed from topset and partially from foreset beds of stratified glaciofluvial deposits. The solum has developed within the topset bed while the coarse gravelly foreset beds are still mostly unweathered (D horizon).

The small accumulation of clay and free oxides in the B horizon, and the distribution and presence of several kinds of clay minerals within the profiles indicate that both soils are relatively young and immature. The higher stage of weathering of the opaque minerals in the Wethersfield, the presence of quartz in the fine clay of the Merrimac, and the physical nature of the Wethersfield substratum compared with the Merrimac suggest the former soil as being somewhat older.

Clay size minerals found in Merrimac soils were illite, montmorillonite, chlorite, vermiculite, kaolin, and gibbsite in order of decreasing abundance. Quartz, feldspar, and muscovite were also found in the clay fractions.

In the Wethersfield soils clay size minerals found were illite, vermiculite, interstratified montmorillonite-chlorite, kaolin, chlorite, and hematite. Quartz and feldspars were absent. The changes in concentration of these minerals from one horizon to another is appreciable for both soils but is not indicative of a high maturity.

Vermiculite appears to be the present end product of weathering in these soils. Although illite predominates in the profile, most of it is inherited from pre-depositional weathering. Some illite has formed from the weathering of biotite and muscovite. The presence of chlorite as an important component of the clay fractions, especially in Merrimac soils, owes its origin primarily to the parent crystalline rocks.

The potential supply of calcium, magnesium, and potassium of these soils is good but the actual rate of release is low. Boron and phosphorus seem to be critical elements.

The slow permeability of the Wethersfield substratum is an important factor contributing to the accelerated erosion occurring on this soil. Little erosion occurs on the Merrimac because of the very rapid internal drainage of its substratum.

Although the clay minerals have a rather high cation exchange capacity, this effect is minimized by the low clay content of these soils.

The higher free MnO content and low permeability of the Wethersfield compared with the Merrimac helps explain why high quality tobacco is not produced on Wethersfield soils.

The Merrimac may be considered a member of the Brown Podzolic great soil group. Apparently, the Wethersfield is more nearly like the European Brown Earths of low base status ("Sol Brun Acide") than either the Brown Podzolic or Gray-Brown Podzolic.

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APPENDIX

Heavy Minerals in the Wethersfield *(Tables 9-14)*

Hornblende

Hornblende is the most abundant heavy mineral in the profile, decreasing gradually with depth and with increasing grain size.

The hornblende grains are generally green to dark green and their pleochroism moderate. (—) 2V is large; the isogyre shows only a slight bend. The wedge cleavage is rarely perceptible. Inclusions are rare. The grains are generally anhedral although a few have some planar surfaces. The nonplanar surfaces are jagged or conchoidal, and no grains exhibit the roundness typical of water-worn grains.

Epidote

Epidote is the second most abundant heavy mineral. In most of the fractions this mineral decreases with depth, especially in the silts. A sharp break from about 5 to 10% concentration in the coarser sands to 15 to 20% in the very fine sands and silts occurs.

Epidote is generally colorless to slightly yellow. Some grains are lemon yellow. The colored grains exhibit moderate to very weak pleochroism. (—) 2V = 70° to 80°; dispersion is marked. The grains are generally bounded by subconchoidal surfaces. None of the grains are rounded.

Opaques

The opaque minerals, ilmenite and magnetite, are third in abundance. In general, they increase with decreasing particle size and with depth. In the coarse and fine silts in the C_1, C_2, and C_3, the opaques comprise more than 60% of the minerals.

Many grains of ilmenite have altered partially or completely to leucoxene. Magnetite is commonly partially decomposed to a brown material, which is probably limonite or goethite. Some grains of magnetite are euhedral, and the crystal faces have a shiny luster. Other grains of magnetite, particularly the highly decomposed ones, are completely rounded.

Garnet

Garnet is the fourth most abundant heavy mineral. Its concentration with depth is irregular, decreasing from about 35 to 40% in the medium sand to about 8% in the medium silt fraction.

Grains with diameters smaller than silt size show little color; larger grains are a light salmon pink color. Inclusions are rare. Grains commonly exhibit growth irregularities both internally and on the surface. Crystals containing dodecahedral and octahedral shaped cavities are present. Some garnet grains have very irregular shapes, and some are pitted with what appears to be percussion marks. It cannot be ascertained whether the roundness of grains is due to water transportation, to original form, or to a previous cycle of deposition. The percussion marks could be due to water transportation or to damage by glacial action. It seems, however, that the distance of transportation could not have been great; otherwise, a few of the growth structures would have been abraded off.

Staurolite

Staurolite is fifth in abundance, decreasing with decreasing particle size. There is some evidence that the concentration is somewhat smaller in the very fine sand and silts. Depth has no apparent effect on distribution.

The color of staurolite is dark to light golden yellow, and pleochroism is strong. Many grains have abundant opaque inclusions. The surfaces of grains are very irregular and show no rounding.

Zoisite

Zoisite is most abundant in the very fine sands. Depth does not seem to have any influence on its distribution.

Zoisite is usually colorless and free of inclusions. Two varieties have been found. One variety has $(+)\ 2V = 20° - 30°$ and marked dispersion (violet greater than red); the other variety has a larger 2V and little or no dispersion. In many cases zoisite and andalusite could not be distinguished, therefore, some of the grains counted as zoisite may be andalusite. Grains of zoisite have irregular bounding surfaces and show no rounding.

Sillimanite

Sillimanite occurs both as individual columnar crystals without terminations, and as aggregates of needle-like crystals. It is usually colorless, although a few of the aggregates are light brown. None of the sillimanite shows rounding. The greatest concentration was found in the upper solum, especially in the very fine sand and silts.

Kyanite

Kyanite is generally colorless, but a few grains are pale green. The right-angle cleavage is well developed in most grains. Inclusions are uncommon. Some grains are partially rounded. This may have been due to water transportation or to their original shape in the parent metamorphic rock.

Tourmaline

Tourmaline was most abundant in the 0.175-0.105 mm size fine sand, very fine sand and coarse silt fractions.

Tourmaline occurs as columnar crystals. The prism faces are well preserved. Many grains, however, are anhedral. The color ranges from dark brown to light brown and light yellow. Pleochroism is marked. Some grains are slightly biaxial. Inclusions are common; some form a linear cluster parallel to the C-axis in the middle of the grains. None of the tourmaline shows rounding.

Zircon

Zircon increased with decreasing particle size, especially in the silt, being practically absent in the two coarser sand fractions.

All grains of zircon are colorless, exhibiting no cleavage and containing no inclusions. Most grains are rounded.

Brookite

No brookite was found in the medium sands and only small amounts to traces in the other fractions.

Brookite is colorless but has an adamantine luster. It occurs as rounded grains.

Rutile

Only small amounts of rutile were found. There is indication that the amount increased slightly with decreasing particle size.

Rutile has an amber color and is dark around the edges. A few euhedral crystals are present, but more generally the grains are anhedral. It has a conchoidal fracture. None of the grains are rounded.

Orthopyroxenes

It is difficult to determine the presence of these minerals because they are generally weathered. Those grains which were determined with certainty had irregular edges. No rounded grains were observed. Only small amounts were found, and orthopyroxenes were absent in some of the horizons.

Clinopyroxenes

The same difficulty was encountered in identifying these minerals as with orthopyroxenes. All grains are weathered and have irregular and unrounded surfaces. Their occurrence is somewhat similar to the orthopyroxenes.

Andalusite

None of this mineral was found in the two coarser sands and the medium silt fractions; 1% was the maximum present in the other fractions.

In several cases it was difficult to distinguish this mineral from zoisite. Andalusite was noted when the sign could be determined. All grains were irregular and showed no rounding.

Apatite

Apatite occurs as colorless anhedral grains. Only small amounts were found in the C_2 and C_3 horizons and none in the other horizons. There was a slight indication that the amount increased with a decrease in particle size, being as much as 6% in the C_2 coarse silt. None occurred in the medium silt.

Heavy Minerals in the Merrimac *(Tables 15-20)*

Hornblende

Hornblende, as in the Wethersfield, is the most abundant heavy mineral. No differences in concentration are noticed with profile depth. It is most abundant, however, in the 0.175 to 0.105 mm fine sand fraction.

The grains are fresh and show no weathering. Very few grains have flat surfaces. They have a high degree of sphericity but no rounding. A few grains have marked prismatic cleavage.

Garnet

Garnet, in contrast to being fourth in abundance in the Wethersfield, is the second most abundant heavy mineral, fluctuating in concentration from one horizon to another. It decreases from about 25 to 30% in concentration in the medium sand to about 8% in the medium silt fraction.

The grains are colorless to salmon pink. Most grains are bounded by conchoidal fracture surfaces and a few have growth structures on the surface. The same problems concerning distance of transportation apply here as for the Wethersfield given above.

Opaque Minerals

The opaques are principally magnetite and ilmenite. As in the Wethersfield, they are third in abundance among heavy minerals. The concentration in the sands is about 10 to 15%, increasing slightly in the silts to about 15 to 18%. The concentration of these minerals does not vary appreciably with depth.

There are a few grains of leucoxene as an alteration product of ilmenite. Magnetite and ilmenite are generally much fresher than those in the Wethersfield. They show little rounding. The freshness of the opaques in the Merrimac as compared with their higher degree of weathering in the Wethersfield seems to indicate that the former soil is the younger.

Epidote

Epidote is the fourth most abundant heavy mineral, being second in the Wethersfield. The concentration of the mineral is constant throughout the profile. It increases distinctly, however, with decreasing particle size.

The mineral occurs generally as equant grains. A few lemon yellow piedmontite grains were observed in the medium and fine sands. Most of them are colorless, but a few are of various shades of yellow and green. The colored grains are moderately pleochroic.

Staurolite

Staurolite, as in the Wethersfield, is the fifth most abundant heavy mineral. This mineral decreases slightly with depth and markedly with decreasing grain size.

The mineral occurs as anhedral, equant grains, that have marked pleochroism. Inclusions are common, and some grains have abundant blebs.

Zircon, Brookite, Tourmaline, Rutile, and Kyanite

These minerals are similar to those found in the Wethersfield.

Zoisite, Andalusite

These two minerals increase appreciably with decrease in particle size from about 1% in the medium sand to about 25% in the medium silt fraction. Their concentration is somewhat lower in the substratum than in the solum.

Sillimanite

Sillimanite occurs as columnar crystals and as aggregates of needle-like crystals. The columnar type increases in amount with decreasing particle size.

TABLE 2. MECHANICAL ANALYSIS OF THE MERRIMAC AND WETHERSFIELD SOILS

Horizon	Depth	Texture	Size class and diameter of particles (in mm)														
				Sand						Silt			Clay				
			Gravel >2	Very coarse 2-1	Coarse 1-0.5	Medium 0.5-0.25	Fine sand: Coarse fract. 0.25-0.175	Fine sand: Fine fract. 0.175-0.105	Fine sand: Very fine 0.105-0.05	Coarse 0.05-0.02	Medium 0.02-0.005	Fine 0.005-0.002	Coarse 0.002-0.0002	Fine <0.0002	Total mineral matter <2	Solution loss[1]	Hygroscopic water, 110°C.
	inches	class	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Merrimac fine sandy loam																	
A_{11}	0-2	f s l	2.4	0.7	6.8	7.8	6.3	6.9	15.3	23.9	14.6	0.2	0.7	2.4	85.6	14.9	2.88
A_{12}	2-3	f s l	0.7	2.2	10.0	9.2	6.9	7.1	12.5	22.7	10.2	0.7	1.5	6.9	89.9	10.1	2.25
A_p	3-8	f s l	0.9	2.4	10.7	9.4	7.4	7.1	12.6	24.9	14.8	0.2	0.6	2.8	92.9	7.1	2.46
B_{22}	8-12	f s l	0.6	2.5	9.2	7.7	6.0	5.9	12.5	30.4	14.8	0.3	0.9	3.7	93.9	6.1	1.32
B_{23}	12-20	f s l	0.9	2.4	11.1	9.5	6.9	6.1	16.8	29.9	5.8	0.4	1.1	6.0	96.0	4.0	2.04
D_1	20-26	l s	2.0	3.1	16.8	20.0	14.8	11.6	10.4	13.7	2.3	0.1	0.6	4.3	97.7	2.3	2.04
D_2	26-33	f s	2.6	1.6	5.0	17.1	26.9	37.4	7.7	1.4	1.5	0	0	0.1	98.7	1.3	2.04
D_3	33-70	c s	13.9	8.1	24.2	18.0	25.0	19.2	3.2	0.8	0.2	0	0	0.7	99.4	0.6	2.04
Wethersfield silt loam																	
A_0	1-0	si l	0	0	0.2	0.3	0.6	3.4	17.0	25.2	16.6	0.9	1.7	1.4	67.3	32.7	8.70
A_1	0-1	si l	3.3	2.0	3.2	2.3	2.1	3.5	11.2	24.0	23.2	2.1	4.1	3.1	80.8	19.2	4.60
B_1	1-4	si l	25.7	1.8	3.4	2.7	2.5	3.8	12.0	26.8	23.8	2.2	5.5	4.7	89.2	10.8	4.17
B_2	4-13	si l	26.4	2.2	4.1	2.8	2.4	4.0	12.5	27.3	26.1	3.2	5.6	5.1	95.3	4.7	1.52
B_3	13-20	si l	33.0	3.3	5.1	3.1	2.9	4.0	14.0	26.3	26.5	3.9	3.9	4.4	97.4	2.6	2.67
C_1	20-30	si l	27.5	2.8	3.9	2.4	2.4	4.0	10.8	23.6	27.4	5.5	5.4	9.7	97.9	2.1	1.42
C_2	30-39	si l	45.5	3.4	4.7	2.8	2.4	4.3	11.4	21.1	26.1	2.8	9.6	9.1	97.7	2.3	1.63
C_3	39-50	si l	22.0	2.8	5.1	3.4	2.7	4.6	11.5	21.7	24.7	4.9	10.9	5.6	97.9	2.1	1.73

[1]Includes free oxides, organic matter and water.

TABLE 3. PHYSICAL PROPERTIES OF THE MERRIMAC AND WETHERSFIELD SOILS[1]

Horizon	Depth sampled	Field moisture[2]	Bulk density	Porosity			Permeability		Penetrability		
				Capillary	Non-capillary	Total	Rate	Class	Depth[3]	Strokes[4]	Penetration/ impact[5]
	inches	%	g/cc	%	%	%	in/hr		inches	no.	inches
Merrimac fine sandy loam											
A_{11}	½-2½	42.8	0.72	59.2	11.9	71.1	16.89	Very rapid	5.2	7.1	0.475
A_p	4-6	21.7	1.09	44.6	12.5	57.2	8.06	Rapid	5.0	4.9	.689
B_{22}	10-12	23.5	1.28	41.9	8.6	50.8	1.42	Moderate	5.3	5.7	.592
B_{23}	16-18	27.6	1.27	47.8	3.6	51.6	1.21	Moderate	5.0	5.1	.662
D_1	21-23	19.5	1.40	43.5	2.6	46.1	1.23	Moderate	4.3	5.5	.614
D_2	26-28	11.5	1.51	31.9	9.8	41.9	4.38	Mod. rapid	4.6	3.1	1.089
D_3	33-35	5.7	1.63	7.6	27.4	35.0	33.22	Very rapid	2.0	6.1	.553
Wethersfield silt loam											
B_1	1-3	31.5	1.01	39.5	20.0	59.7	17.14	Very rapid	4.8	6.8	0.496
B_2	6-8	22.3	1.27	35.9	13.8	49.7	3.91	Mod. rapid	6.9	7.0	.482
B_3	13-15	20.4	1.43	38.3	6.4	44.8	1.42	Moderate	4.2	10.2	.331
C_1	22-24	17.2	1.58	33.5	6.3	40.1	0.99	Moderate to slow	2.2	26.5	.127
C_1	25-27	12.6	1.81	27.5	3.6	31.0	0.16	Slow	1.2	34.0	.099

[1]Average of five determinations, except six determinations for the Roto-Tiller apparatus.
[2]Moisture in soil when sampled.
[3]Inches penetration of Roto-Tiller apparatus (31).
[4]Number of times required to lift a 12-pound hammer 2 feet to drive a 3-5/16-inch diameter core sampler 3-3/8 inches into soil (45).
[5]Average penetration of the core sampler for each impact of the 12-pound hammer.

TABLE 4. CHEMICAL PROPERTIES OF THE MERRIMAC AND WETHERSFIELD SOILS[1]

Horizon	Depth inches	Acidity	C	N	C/N ratio	Milliequivalents per 100 gms soil							Base saturation	Available P
						C.E.C.[2]	H+	Na+	K+	Mg++	Ca++	S+[3]		
		pH	%	%									%	ppm
Merrimac fine sandy loam														
A_{11}	0-2	3.7	5.34	0.21	25.4	25.8	15.0	0.05	0.42	0.30	0.34	16.11	7	16
A_{12}	2-3	4.3	2.61	0.12	21.7	13.4	11.7	0.03	0.13	0.18	0.23	12.27	5	14
A_p	3-8	4.6	0.95	0.06	15.8	5.5	5.0	0.03	0.36	0.12	0.15	5.66	12	10
B_{22}	8-12	4.5	0.53	0.03	17.7	4.5	3.9	0.02	0.18	0.08	0.06	4.24	8	60
B_{23}	12-20	4.6	0.26	0.01	26.0	3.1	2.4	0.04	0.22	0.05	0.12	2.83	15	26
D_1	20-26	4.8	0.08	....	....	1.8	1.3	0.01	0.09	0	0.12	1.52	14	20
D_2	26-33	4.9	0.07	....	....	0.8	0.9	0.01	0.04	0	0.10	1.05	14	32
D_3	33-70	4.9	0.02	....	....	....	....	....	....	0.05	0.06	....	....	18
Wethersfield silt loam														
A_0	1-0	4.4	22.57	0.65	34.7	50.3	30.9	0.14	1.51	2.48	11.7	46.73	....	124
A_1	0-1	4.2	7.40	0.32	23.1	17.8	14.1	0.07	0.43	0.52	0.58	15.70	10	76
B_1	1-4	4.4	2.86	0.11	26.0	10.1	8.2	0.07	0.16	0.19	0.26	8.88	7	84
B_2	4-13	4.4	0.56	0.05	11.2	4.6	4.0	0.06	0.09	0.10	0.35	4.60	11	52
B_3	13-20	4.6	0.12	0.02	6.0	4.3	3.6	0.08	0.11	0.43	0.46	4.68	23	32
C_1	20-30	4.6	0.14	0.01	14.0	8.5	5.4	0.09	0.11	1.55	1.22	8.37	35	18
C_2	30-39	4.6	0.07	0.01	7.0	10.3	4.0	0.18	0.12	3.15	3.53	10.98	63	112
C_3	39-50	5.1	0.09	0.01	9.0	10.6	2.0	0.26	0.10	4.14	5.62	12.12	83	152

[1]Analyses by S. Schwartz and H. G. M. Jacobson, except C analyses by U.S.D.A. Bureau of Plant Industry, Soils and Agricultural Engineering. Data reported on an oven-dry weight basis.

[2]Cation exchange capacity.

[3]Sum of cations.

TABLE 5. FREE OXIDES[1] IN WETHERSFIELD AND MERRIMAC SOILS

Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MnO	Total
	inches	%	%	%	%	%
		Merrimac fine sandy loam				
A_{11}	0-2	0.29	1.43	1.25	0.01	2.98
A_{12}	2-3	0.41	1.47	1.42	0.01	3.31
A_p	3-8	0.42	1.49	1.61	0.01	3.53
B_{22}	8-12	0.67	1.68	1.80	0.01	4.16
B_{23}	12-20	0.35	1.19	1.55	0.01	3.10
D_1	20-26	0.29	0.69	0.91	0.01	1.90
D_2	26-33	0.30	0.78	0.62	0.02	1.72
D_3	33-70	0.41	0.50	0.50	0.02	1.43
		Wethersfield silt loam				
A_0	1-0	0.25	1.22	1.88	0.12	3.47
A_1	0-1	0.18	1.35	2.13	0.13	3.79
B_1	1-4	0.88	1.47	2.25	0.07	4.67
B_2	4-13	0.75	0.73	1.14	0.02	2.64
B_3	13-20	0.36	1.13	0.62	0.04	2.15
C_1	20-30	0.48	0.64	0.44	0.03	1.59
C_2	30-39	0.44	0.82	0.44	0.06	1.76

[1]Extraction by Jeffries' method (26). Results based on duplicate 2.0 g samples of non-fractionated soil.

TABLE 6. CATION EXCHANGE CAPACITY OF SELECTED SILT AND CLAY FRACTIONS OF THE MERRIMAC AND WETHERSFIELD SOILS

Horizon	Depth	Fine silt 5-2 μ	Clay	
			Coarse fraction 2-0.2 μ	Fine fraction <0.2 μ
	inches	m e[1]	m e	m e
		Merrimac fine sandy loam		
A_{11}	0-2	20.0	54.7	62.4
A_{12}	2-3	20.0	43.3	62.0
A_p	3-8	17.4	33.5	51.7
B_{22}	8-12	15.5	34.6	46.0
B_{23}	12-20	14.0	32.7	45.4
D_1	20-26	35.3	24.0	48.9
D_2	26-33	22.1	24.4	52.2
D_3	33-70	16.1	10.4	40.5
		Wethersfield silt loam		
A_0	1-0	17.4	28.8	52.3
A_1	0-1	16.0	29.3	48.0
B_1	1-4	14.5	31.3	43.0
B_2	4-13	12.9	27.2	43.7
B_3	13-20	13.3	23.6	37.2
C_1	20-30	11.6	23.0	38.3
C_2	30-39	12.1	28.5	36.0
C_3	39-50	18.3	26.6	36.1

[1]Milliequivalents per 100 grams of oven-dry soil.

Table 7. Total Potassium of Selected Silt and Clay Fractions of the Merrimac and Wethersfield Soils

Horizon	Depth	Fine silt 5-2 μ	Clay	
			Coarse fraction 2-0.2 μ	Fine fraction $<$0.2 μ
	inches	%	%	%
		Merrimac fine sandy loam		
A_{11}	0-2	2.10	1.79	1.35
A_{12}	2-3	2.26	1.90	1.16
A_p	3-8	1.54	1.84	1.11
B_{22}	8-12	2.71	1.74	1.13
B_{23}	12-20	2.72	2.28	1.53
D_1	20-26	3.37	2.60	2.16
D_2	26-33	3.23	1.84	0.42
D_3	33-70	3.06	1.31	....
		Wethersfield silt loam		
A_0	1-0	2.35	2.06	2.14
A_1	0-1	2.60	2.48	1.82
B_1	1-4	2.69	2.29	2.39
B_2	4-13	2.95	2.88	2.33
B_3	13-30	3.22	4.09	3.05
C_1	20-30	3.64	4.73	3.80
C_2	30-39	3.25	4.83	3.96
C_3	39-50	3.68	4.76	3.84

TABLE 8. CONTENT OF HEAVY MINERALS (Sp. Gr. >2.95) IN MERRIMAC AND WETHERSFIELD SOILS

Horizon	Depth	Diameter of particles in mm						
			Fine sand			Silt		
		Medium sand 0.5-0.25	coarse fraction 0.025-0.175	fine fraction 0.175-0.105	Very fine sand 0.105-0.05	Coarse 0.05-0.02	Medium 0.02-0.005	Total[1]
	inches	%	%	%	%	%	%	%
				Merrimac fine sandy loam				
A_{11}	0-2	3.0	4.6	7.4	5.7	9.2	1.9	4.4
A_{12}	2-3	3.2	5.6	8.0	7.0	8.8	1.8	4.3
A_p	3-8	3.4	5.1	9.2	7.4	9.3	1.4	4.8
B_{22}	8-12	3.5	5.2	8.2	6.4	9.4	1.5	4.9
B_{23}	12-20	3.0	5.7	9.1	5.4	10.4	1.5	5.3
D_1	20-26	3.6	7.9	9.1	9.7	11.1	2.7	5.5
D_2	26-33	2.4	3.8	8.5	32.5	15.0	2.0	7.3
D_3	33-70	4.0	3.1	7.7	17.7	6.5	1.2	3.6
				Wethersfield silt loam				
A_0	....	0.8	1.6	3.8	3.9	4.6	1.8	2.3
A_1	0-1	2.0	2.5	3.0	2.8	4.2	0.22	1.6
B_1	1-4	2.7	2.7	3.6	3.5	4.3	0.28	1.9
B_2	4-13	2.7	2.5	2.5	2.8	4.4	0.34	1.8
B_3	13-20	1.0	1.7	2.3	2.2	2.9	0.12	1.3
C_1	20-30	1.4	0.9	1.6	1.4	2.2	0.08	1.1
C_2	30-39	1.4	1.1	1.3	1.5	2.2	0.08	0.8
C_3	39-50	1.0	0.8	1.5	1.2	2.1	0.10	0.7

[1]Sum total of heavy minerals determined in each textural fraction indicated above expressed as percent of total sample (dry basis).

TABLE 9. PER CENT OF HEAVY MINERALS IN THE MEDIUM SANDS (0.5-0.25 mm) OF THE WETHERSFIELD SILT LOAM

Horizon	A_1	B_1	B_2	B_3	C_1	C_2	C_3
Depth — inches	0-1	1-4	4-13	13-20	20-30	30-39	39-50
Hornblende	19	18	25	20	11	8	8
Garnet	34	40	37	30	47	45	45
Epidote	5	2	4	6	4	1	1
Staurolite	6	9	4	15	6	12	12
Zoisite	0	1	0	0	0	1	0
Sillimanite	0	1	0	0	0	1	0
Kyanite	3	2	2	1	0	1	1
Tourmaline	0	2	2	0	0	0	2
Zircon	0	0	0	0	0	0	1
Brookite	0	0	0	0	0	0	0
Rutile	0	1	0	0	0	0	0
Orthopyroxene	0	2	0	0	2	0	0
Clinopyroxene	1	0	2	0	0	1	0
Andalusite	0	0	0	0	0	0	0
Chlorite	0	0	0	0	0	0	0
Apatite	0	0	0	0	0	0	1
Opaques	32	22	24	28	30	30	29
Total	100	100	100	100	100	100	100

TABLE 10. PER CENT OF HEAVY MINERALS IN THE FINE SANDS, COARSE FRACTION (0.25-0.175 mm) OF THE WETHERSFIELD SILT LOAM

Horizon	A_1	B_1	B_2	B_3	C_1	C_2	C_3
Depth – inches	0-1	1-4	4-13	13-20	20-30	30-39	39-50
Hornblende	28	22	21	20	21	13	10
Garnet	33	37	34	35	28	31	38
Epidote	5	6	6	4	6	4	7
Staurolite	8	8	12	12	6	5	4
Zoisite	1	t[1]	t	t	1	0	1
Sillimanite	1	2	2	0	0	1	0
Kyanite	1	1	2	1	1	1	1
Tourmaline	2	2	1	t	0	0	0
Zircon	0	0	0	0	0	0	0
Brookite	0	1	t	0	1	0	0
Rutile	t	0	0	0	0	1	1
Orthopyroxene	t	0	t	t	1	1	1
Clinopyroxene	t	1	0	2	0	1	1
Andalusite	0	0	0	0	0	0	0
Chlorite	0	t	0	1	1	0	0
Apatite	0	0	0	0	0	1	2
Opaques	21	20	22	25	34	41	34
Corundum	0	0	t	0	0	0	0
Total	100	100	100	100	100	100	100

[1]Present in trace amount.

TABLE 11. PER CENT OF HEAVY MINERALS IN THE FINE SANDS, FINE FRACTION (0.175-0.105 mm) OF THE WETHERSFIELD SILT LOAM

Horizon	A_0	A_1	B_1	B_2	B_3	C_1	C_2	C_3
Depth – inches	1-0	0-1	1-4	4-13	13-20	20-30	30-39	39-50
Hornblende	44	32	29	27	25	30	16	16
Garnet	14	26	28	26	22	19	26	32
Epidote	9	10	8	11	13	14	8	8
Staurolite	4	4	7	7	9	5	5	5
Zoisite	1	2	2	1	1	1	2	2
Sillimanite	0	0	1	1	1	1	0	t[1]
Kyanite	1	2	3	2	2	1	1	2
Tourmaline	2	2	2	1	2	3	1	1
Zircon	1	0	0	t	t	t	0	0
Brookite	2	t	1	t	0	0	t	0
Rutile	t	2	1	1	t	t	t	1
Orthopyroxene	0	0	0	0	0	0	1	t
Clinopyroxene	1	2	1	t	0	0	2	t
Andalusite	0	0	0	t	0	0	t	0
Chlorite	0	0	0	0	1	0	0	0
Apatite	0	0	0	0	0	0	3	4
Opaques	21	18	17	23	24	26	35	29
Total	100	100	100	100	100	100	100	100

[1]Present in trace amount.

TABLE 12. PER CENT OF HEAVY MINERALS IN THE VERY FINE SANDS (0.105-0.05 mm) OF THE WETHERSFIELD SILT LOAM

Horizon	A_0	A_1	B_1	B_2	B_3	C_1	C_2	C_3
Depth – inches	1-0	0-1	1-4	4-13	13-20	20-30	30-39	39-50
Hornblende	47	40	24	27	29	22	11	16
Garnet	8	12	13	9	8	7	9	10
Epidote	19	17	18	22	10	17	13	11
Staurolite	3	2	4	4	3	3	3	3
Zoisite	6	3	6	3	4	5	3	3
Sillimanite	2	t[1]	2	1	2	1	0	t
Kyanite	t	1	2	t	1	2	t	1
Tourmaline	2	4	5	2	3	6	3	5
Zircon	3	3	4	3	6	0	1	3
Brookite	1	1	t	0	1	t	0	0
Rutile	t	t	1	1	1	1	1	1
Orthopyroxene	0	1	t	1	4	3	t	t
Clinópyroxene	0	0	0	t	2	1	0	t
Andalusite	0	0	1	0	t	1	0	0
Chlorite	t	1	1	2	1	t	0	0
Apatite	0	0	0	t	0	0	5	5
Opaques	9	15	19	25	25	31	51	42
Total	100	100	100	100	100	100	100	100

[1]Present in trace amount.

TABLE 13. PER CENT OF HEAVY MINERALS IN THE COARSE SILT (0.05-0.02 mm) OF THE WETHERSFIELD SILT LOAM

Horizon	A_0	A_1	B_1	B_2	B_3	C_1	C_2	C_3
Depth – inches	1-0	0-1	1-4	4-13	13-20	20-30	30-39	39-50
Hornblende	50	31	25	29	19	11	9	7
Garnet	3	6	5	4	4	2	2	2
Epidote	22	28	20	20	19	5	5	10
Staurolite	2	1	2	1	2	1	2	1
Zoisite	4	1	4	2	2	2	1	2
Sillimanite	1	1	1	1	t[1]	t	0	0
Kyanite	2	2	0	1	2	1	0	0
Tourmaline	2	4	5	4	7	5	3	6
Zircon	1	5	6	5	2	4	5	4
Brookite	t	0	t	1	1	1	t	0
Rutile	0	2	2	2	1	1	2	4
Orthopyroxene	t	0	t	0	0	0	0	0
Clinopyroxene	t	0	t	t	t	0	0	0
Andalusite	1	1	1	0	1	0	0	1
Chlorite	0	0	t	0	0	1	t	0
Apatite	0	0	0	0	0	0	6	1
Opaques	12	18	29	30	40	66	65	62
Total	100	100	100	100	100	100	100	100

[1]Present in trace amount.

TABLE 14. PER CENT OF HEAVY MINERALS IN THE MEDIUM SILT (0.02-0.005 mm) OF THE WETHERSFIELD SILT LOAM

Horizon	A_0	A_1	B_1	B_2	B_3	C_1	C_2	C_3
Depth — inches	1-0	0-1	1-4	4-13	13-20	20-30	30-39	39-50
Hornblende	29	11	10	2	16	5	10	6
Garnet	7	8	8	11	2	1	9	2
Epidote	17	25	17	24	9	4	14	5
Staurolite	0	1	2	0	1	0	0	0
Zoisite	t[1]	2	1	2	t	0	1	1
Sillimanite	4	2	2	0	0	0	0	t
Kyanite	1	2	0	2	0	0	t	0
Tourmaline	4	t	t	0	1	t	t	0
Zircon	10	7	3	4	6	1	5	6
Brookite	0	t	1	0	0	0	0	0
Rutile	1	2	1	2	1	t	t	0
Orthopyroxene	0	0	0	0	0	0	0	0
Clinopyroxene	2	t	0	0	1	1	1	1
Andalusite	0	0	0	0	0	0	0	0
Chlorite	0	0	0	0	0	0	0	0
Apatite	0	0	0	0	0	0	0	0
Opaques	25	40	55	53	63	88	60	79
Total	100	100	100	100	100	100	100	100

[1]Present in trace amount.

TABLE 15. PER CENT OF HEAVY MINERALS IN THE MEDIUM SANDS (0.5-0.25 mm) OF THE MERRIMAC FINE SANDY LOAM

Horizon	A_{11}	A_{12}	A_p	B_{22}	B_{23}	D_1	D_2	D_3
Depth — inches	0-2	2-3	3-8	8-12	12-20	20-26	26-33	33-70
Hornblende	34	35	34	41	41	37	36	34
Garnet	31	27	30	29	25	27	23	35
Epidote	6	9	8	9	6	8	10	4
Staurolite	11	8	9	3	7	9	7	6
Zircon	t[1]	0	t	0	0	0	0	0
Brookite	0	0	0	0	0	0	t	0
Tourmaline	t	1	1	t	1	0	2	2
Rutile	0	0	0	0	0	0	0	0
Kyanite	6	4	3	3	4	2	1	t
Zoisite and Andalusite	1	1	1	1	1	2	t	0
Sillimanite (fibrous)	1	0	1	2	t	2	1	1
Sillimanite (columnar)	0	1	t	t	t	1	0	0
Chlorite	0	0	t	0	0	0	0	0
Opaques	8	10	12	10	12	10	15	14
Clinopyroxene	2	4	1	2	3	2	5	4
Piedmontite	t	0	0	t	0	0	0	0
Hypersthene	0	t	0	0	0	0	0	0
Apatite	0	0	0	0	0	0	t	t
Total	100	100	100	100	100	100	100	100

[1]Present in trace amount.

TABLE 16. PER CENT OF HEAVY MINERALS IN THE FINE SANDS, COARSE FRACTION (0.25-0.175 mm) OF THE MERRIMAC FINE SANDY LOAM

Horizon	A_{11}	A_{12}	A_p	B_{22}	B_{23}	D_1	D_2	D_3
Depth — inches	0-2	2-3	3-8	8-12	12-20	20-26	26-33	33-70
Hornblende	43	45	45	45	43	44	53	51
Garnet	21	19	21	24	19	19	11	18
Epidote	11	7	10	6	8	13	7	.10
Staurolite	6	9	6	3	5	5	4	3
Zircon	1	t[1]	1	0	0	0	t	0
Brookite	0	0	0	0	t	t	t	0
Tourmaline	2	1	2	1	3	3	2	t
Rutile	0	0	0	0	0	t	0	0
Kyanite	1	2	2	t	2	t	1	2
Zoisite and Andalusite	t	1	2	1	t	1	2	1
Sillimanite (fibrous)	1	t	0	1	1	0	1	1
Sillimanite (columnar)	0	0	0	t	1	1	2	t
Chlorite	0	t	0	t	0	0	0	t
Opaques	13	15	8	15	14	11	13	12
Piedmontite	t	0	0	t	1	1	0	0
Hypersthene	t	0	0	0	t	t	0	0
Clinopyroxene	1	1	3	4	3	2	4	2
Apatite	0	0	0	0	t	0	0	0
Corundum	0	0	0	0	0	t	0	0
Total	100	100	100	100	100	100	100	100

[1]Present in trace amount.

TABLE 17. PER CENT OF HEAVY MINERALS IN THE FINE SANDS, FINE FRACTION (0.175-0.105 mm) OF THE MERRIMAC FINE SANDY LOAM

Horizon	A_{11}	A_{12}	A_p	B_{22}	B_{23}	D_1	D_2	D_3
Depth — inches	0-2	2-3	3-8	8-12	12-20	20-26	26-33	33-70
Hornblende	46	50	47	48	39	48	52	61
Garnet	18	14	19	19	18	17	16	6
Epidote	12	10	11	6	13	9	10	11
Staurolite	4	5	3	5	4	6	2	4
Zircon	0	1	0	0	0	0	2	1
Brookite	1	1	t[1]	0	2	2	t	t
Tourmaline	1	2	1	0	1	t	1	t
Rutile	1	t	0	1	t	0	t	0
Kyanite	4	2	t	2	t	1	t	2
Zoisite and Andalusite	1	0	3	2	2	1	2	2
Sillimanite (fibrous)	t	2	0	t	1	0	0	1
Sillimanite (columnar)	t	t	t	1	t	1	1	0
Chlorite	t	0	t	0	t	t	1	t
Opaques	11	13	12	13	16	10	13	9
Piedmontite	1	0	1	1	1	1	0	t
Clinopyroxene	0	0	3	2	3	4	0	2
Apatite	0	0	0	0	0	0	0	1
Total	100	100	100	100	100	100	100	100

[1]Present in trace amount.

TABLE 18. PER CENT OF HEAVY MINERALS IN THE VERY FINE SANDS (0.105-0.05 mm) OF THE MERRIMAC FINE SANDY LOAM

Horizon	A_{11}	A_{12}	A_p	B_{22}	B_{23}	D_1	D_2	D_3
Depth — inches	0-2	2-3	3-8	8-12	12-20	20-26	26-33	33-70
Hornblende	44	43	48	47	39	47	28	39
Garnet	9	8	9	10	8	8	23	18
Epidote	19	13	14	21	21	18	11	14
Staurolite	1	4	2	2	5	t[1]	3	2
Zircon	3	t	t	1	1	1	4	2
Brookite	t	2	t	0	t	1	3	1
Tourmaline	1	2	1	t	t	1	1	0
Rutile	0	2	t	0	t	1	2	3
Kyanite	4	4	3	3	1	2	1	2
Zoisite and) Andalusite)	6	5	3	2	4	4	1	2
Sillimanite (fibrous)	t	t	0	0	2	0	0	1
Sillimanite (columnar)	t	2	3	1	2	1	0	0
Chlorite	3	3	5	2	6	2	2	3
Opaques	10	12	12	11	11	14	21	13
Total	100	100	100	100	100	100	100	100

[1]Present in trace amount.

TABLE 19. PER CENT OF HEAVY MINERALS IN THE COARSE SILT (0.05-0.02 mm) OF THE MERRIMAC FINE SANDY LOAM

Horizon	A_{11}	A_{12}	A_p	B_{22}	B_{23}	D_1	D_2	D_3
Depth — inches	0-2	2-3	3-8	8-12	12-20	20-26	26-33	33-70
Hornblende	29	33	34	35	42	40	33	24
Garnet	6	3	4	3	1	5	10	13
Epidote	11	14	14	14	13	14	16	13
Staurolite	t	0	0	2	t[1]	t	2	1
Zircon	2	0	t	2	0	2	2	5
Brookite	0	0	0	0	0	t	1	3
Tourmaline	1	2	2	2	3	3	2	3
Rutile	3	3	4	1	3	t	0	2
Kyanite	3	3	1	3	1	5	1	1
Zoisite and) Andalusite)	22	22	24	20	23	13	10	22
Sillimanite (fibrous)	0	0	0	0	0	0	t	t
Sillimanite (columnar)	1	1	3	2	3	3	1	1
Chlorite	4	3	2	3	1	2	3	2
Opaques	18	16	12	13	10	13	19	10
Sphene	0	0	t	0	0	0	0	0
Total	100	100	100	100	100	100	100	100

[1]Present in trace amount.

TABLE 20. PER CENT OF HEAVY MINERALS IN THE MEDIUM SILT (0.02-0.005 mm) OF THE MERRIMAC FINE SANDY LOAM

Horizon	A_{11}	A_{12}	A_p	B_{22}	B_{23}	D_1	D_2	D_3
Depth – inches	0-2	2-3	3-8	8-12	12-20	20-26	26-33	33-70
Hornblende	20	8	13	15	31	31	30	34
Garnet	8	7	10	6	4	7	5	9
Epidote	14	15	14	15	10	15	14	17
Staurolite	2	3	1	2	0	t[1]	0	1
Zircon	2	1	3	2	1	3	1	2
Brookite	0	0	0	0	0	t	t	0
Tourmaline	2	4	6	4	0	3	3	1
Rutile	2	5	3	2	3	1	2	0
Kyanite	t	t	0	t	0	1	0	2
Zoisite and) Andalusite)	24	27	23	24	23	22	28	13
Sillimanite (fibrous)	0	0	0	t	0	0	0	0
Sillimanite (columnar)	5	10	12	13	3	2	1	1
Chlorite	1	2	1	1	t	2	1	1
Opaques	20	18	14	16	25	13	15	15
Anatase	0	0	0	0	t	0	0	0
Apatite	0	0	0	0	0	0	0	2
Clinopyroxene	0	0	0	0	0	0	0	2
Total	100	100	100	100	100	100	100	100

[1]Present in trace amount.

TABLE 21. PER CENT OF LIGHT MINERALS (Sp. Gr. <2.95) IN THE MERRIMAC FINE SANDY LOAM

Horizon	A_{11}	A_{12}	A_p	B_{22}	B_{23}	D_1	D_2	D_3
Depth — inches	0-2	2-3	3-8	8-12	12-20	20-26	26-33	33-70
Medium sand (0.5-0.25 mm)								
Quartz	84	88	86	85	84	80	81	79
Microcline	13	11	12	10	9	16	13	16
Orthoclase	1	0	0	t[1]	0	0	0	0
Muscovite	t	t	t	2	2	1	2	2
Biotite	t	t	0	1	3	t	2	2
Plagioclase, An_{10}	t	t	1	0	0	0	1	0
Plagioclase, An_{20}	2	1	t	2	2	3	t	t
Plagioclase, An_{30}	t	0	1	0	0	t	1	1
Plagioclase, An_{40}	0	0	0	0	0	t	0	0
Total	100	100	100	100	100	100	100	100
Fine sand, coarse fraction (0.25-0.175 mm)								
Quartz	81	82	78	92	84	83	79	78
Microcline	14	15	14	7	8	12	17	17
Orthoclase	2	t	2	0	t	t	0	t
Muscovite	1	t	2	t	2	1	2	2
Biotite	1	2	1	1	4	3	2	3
Plagioclase, An_{20}	1	1	2	t	0	t	0	t
Plagioclase, An_{30}	0	0	1	0	1	1	t	t
Plagioclase, An_{40}	0	0	0	0	1	t	0	0
Total	100	100	100	100	100	100	100	100
Fine sand, fine fraction (0.175-0.105 mm)								
Quartz	73	72	81	72	67	81	79	72
Microcline	16	23	12	14	10	12	16	16
Orthoclase	2	1	0	1	1	1	t	2
Muscovite	5	t	2	6	10	1	t	2
Biotite	3	2	2	7	11	4	3	7
Plagioclase, An_{10}	1	t	0	0	0	0	0	0
Plagioclase, An_{20}	t	2	2	0	1	t	2	t
Plagioclase, An_{30}	t	0	1	0	t	t	0	1
Plagioclase, An_{40}	0	0	0	0	0	1	0	0
Total	100	100	100	100	100	100	100	100

[1]Present in trace amount.

TABLE 21. PER CENT OF LIGHT MINERALS (Sp. Gr. <2.95) IN THE MERRIMAC FINE SANDY LOAM (Cont.)

Horizon	A_{11}	A_{12}	A_p	B_{22}	B_{23}	D_1	D_2	D_3
Depth — inches	0-2	2-3	3-8	8-12	12-20	20-26	26-33	33-70
				Very fine sand (0.105-0.05 mm)				
Quartz	72	65	61	65	64	63	76	61
Microcline	14	16	16	12	14	20	15	16
Orthoclase	2	2	1	0	1	1	t	t
Muscovite	6	9	14	11	10	8	3	4
Biotite	5	7	8	12	10	8	6	18
Chlorite	t	0	t	t	1	t	0	t
Plagioclase, An_{10}	0	0	0	0	0	0	0	1
Plagioclase, An_{20}	1	1	0	t	t	0	0	t
Plagioclase, An_{40}	t	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100
				Coarse silt (0.05-0.02 mm)				
Quartz	71	79	64	71	67	61	59	55
Microcline	14	9	25	17	17	27	25	29
Orthoclase	0	t	0	0	t	t	0	0
Muscovite	14	10	9	10	13	10	9	7
Biotite	1	2	1	2	2	2	7	9
Chlorite	0	0	0	0	1	0	t	0
Plagioclase, An_{10}	0	0	1	t	0	0	t	t
Plagioclase, An_{30}	0	t	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100
				Medium silt (0.02-0.005 mm)				
Quartz	78	71	67	70	75	70	66	64
Microcline) Orthoclase)	11	12	10	12	9	11	10	5
Muscovite	10	15	17	15	13	14	12	10
Biotite	1	2	6	3	3	5	12	21
Chlorite	0	0	0	0	0	t	0	0
Total	100	100	100	100	100	100	100	100